Vol. 3 OCTOBER, 1920 No. 10

Journal

—OF THE—

American Ceramic Society

A Monthly Journal devoted to the Arts and Sciences Related to the Silicate Industries

COMMITTEE ON PUBLICATIONS

HOMER F. STALEY, Editor
Box 7, U St. Sta., Washington, D. C.

L. E. BARRINGER, *Chairman*,
General Electric Co., Schenectady, N. Y.

A. V. BLEININGER,
Bureau of Standards, Washington, D. C.

H. RIES,
Cornell University, Ithaca, N. Y.

E. W. TILLOTSON,
Mellon Institute, Pittsburgh, Pa.

CONTENTS

Page

Editorials:

Scientific Experts and the Government Service 781

Original Papers and Discussions:

Certain Relations between Chemical Composition and Refractivity in Optical Glasses—Wright 783

The Construction of a Novel Testing Furnace—Walton 833

The Rate of Vitrification of Porcelain Molded under Different Conditions—Sherwood 837

Oil Firing of Kilns—Whitaker 842

Ceramic Abstracts 847

Activities of the Society:

Important Actions of the Board of Trustees at the Chicago Meeting, August 16, 1920 859

New Members Received during September 859

The Entertainment of the Ladies at the Next Convention 860

The Society at the Chemical Exposition 860

Meeting of the Northern Ohio Section 861

Published Monthly by the
AMERICAN CERAMIC SOCIETY
Publication Office: 211 Church St., Easton, Pa.

SIX DOLLARS PER YEAR (Foreign Postage Additional) *SINGLE NUMBERS, SIXTY CENTS*

Entered as second-class matter, July 15, 1918, at the postoffice at Easton, Pa., under the Act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized August 16, 1918.

Copyright, 1920, American Ceramic Society

AMERICAN CERAMIC SOCIETY

OFFICERS, 1920-1921

President: R. H. Minton, General Ceramics Co., Metuchen, N. J.
Vice-President: E. T. Montgomery, Montgomery Porcelain Products Co., Franklin, Ohio.
Treasurer: R. K. Hursh, University of Illinois, Urbana, Ill.
Secretary: C. F. Binns, Alfred University, Alfred, N. Y.
Board of Trustees: The President, Vice-President, Treasurer, and R. D. Landrum, M. F. Beecher, F. H. Riddle, H. F. Staley and R. T. Stull.

OFFICERS OF INDUSTRIAL DIVISIONS

Enamels.—E. P. Poste, *Chairman*, Elyria Enameled Products Co., Elyria, O.; R. R. Danielson, *Secretary*, Bureau of Standards, Washington, D. C.

Glass.—S. R. Scholes, *Chairman*, Utility Glass Works, Lonaconing, Md.; E. W. Tillotson, *Secretary*, Mellon Institute, Pittsburgh, Pa.

Refractories.—A. V. Bleininger, *Chairman*, Homer Laughlin China Co., Newall, W. Va., R. M. Howe, *Secretary*, Mellon Institute, Pittsburgh, Pa.

Terra Cotta.—F. B. Ortman, *Chairman*, Northwestern Terra Cotta Co., Chicago, Ill.; R. L. Clare, *Secretary*, Federal Terra Cotta Co., Woodbridge, N. J.

Brick and Tile.—Marion W. Blair, *Chairman*, 411 Front St., Ridgway, Pa.; W. W. Ittner, *Secretary*, 5500 Pershing Ave., St. Louis, Mo.

White Ware, including Floor and Wall Tile.—F. W. Walker, Jr., *Chairman*, Beaver Falls Art Tile Company, Beaver Falls, Pa.

OFFICERS OF LOCAL SECTIONS

Section	Chairman	Secretary	Councilor
Pittsburgh District	C. R. Peregrine	C. C. Vogt	F. W. Walker, Sr.
Northern Ohio	A. F. Gorton	C. H. Stone, Jr.	R. D. Landrum
St. Louis	I. A. Krusen	G. R. Truman	C. W. Berry
New England	C. J. Hudson	M. C. Booze	M. F. Beecher
Central Ohio	M. B. Cheney	J. D. Whitmer	A. S. Watts
Chicago	H. T. Bellamy	F. L. Steinhoff	C. W. Parmelee
New York State	S. C. Linbarger	J. B. Shaw	L. E Barringer
Eastern	Abel Hansen	G. H. Brown	C. A. Bloomfield

STANDING COMMITTEES

Research and Development.—A. V. Bleininger, *Chairman*, Homer Laughlin China Co., Newall, W. Va.; P. H. Bates, G. H. Brown, Wm. M. Clark, R. M Howe, J. S. Laird, R. B Sosman, R. T. Stull, E. W. Washburn, A. S. Watts.

Rules.—A. S Watts, *Chairman*, Ohio State University, Columbus, O.; R. L. Clare R. K. Hursh, T. A. Klinefelter, J. B. Shaw.

Cooperation.—E. W. Washburn, *Chairman*, University of Illinois, Urbana, Ill.; S. G. Burt, F. B. Dunn, W. E. Emley, H. E. Maddock, T Poole Maynard, G. A. Rankin, J. W. Sanders, F. L. Steinhoff, D. F. Stevens, F. W. Walker, Jr.

Standards.—M. F. Beecher, *Chairman*, Norton Co., Worcester, Mass.; C. W. Berry, M. C. Booze, E. E. F. Creighton, R. R. Danielson, E. C. Hill, R. M. Howe, R. K. Hursh, F. H. Riddle, J. B. Shaw, O. J. Whittemore, Hewitt Wilson.

Publications.—L. E. Barringer, *Chairman*, General Electric Co., Schenectady, N. Y.; A. V. Bleininger, H. Ries, H. F. Staley, E. W. Tillotson.

Sections and Divisions.—S. C. Linbarger, *Chairman*, Carborundum Co., Niagara Falls, N. Y.; C. C. Ashbaugh, Leslie Brown, F. A. Kirkpatrick, R. D. Landrum, A. T. Malm, G. D. Morris, F. B. Ortman, C. W. Parmelee, E. P. Poste, E. W. Tillotson.

Membership.—F. H. Riddle, *Chairman*, Jeffrey-Dewitt Co., Detroit, Mich.; L. J. Frost, H. K. Kimble, A. A. Klein, S. C. Linbarger, Athoil McBean, F. H. Rhead, T. H. Sant, S. R. Scholes, Frederick Stanger, August Staudt, D. F. Stevens, Gail R. Truman, J. D. Whitmer.

Papers and Program.—R. H. Minton, *Chairman*, General Ceramics Co., Metuchen, N. J., and the Chairman of the Industrial Divisions, the Secretaries of the Local Sections and the Secretary of the Society.

JOURNAL
OF THE
AMERICAN CERAMIC SOCIETY

A monthly journal devoted to the arts and sciences related to the silicate industries.

Vol. 3 **October, 1920** **No. 10**

EDITORIAL

SCIENTIFIC EXPERTS AND THE GOVERNMENT SERVICE

There has come to the attention of the office of the Director of the Bureau of Standards, a very general and wholesome protest against Dr. A. V. Bleininger leaving the government employ. This protest is generally so worded as to very much encourage the belief that the ceramics industry is inspired by a common soul that has an interest not only in the industry but in humanity.

One common point is made that Dr. Bleininger has been working for years, very largely at government expense and with facilities furnished by the government, to help the entire industry of the country, and it is asserted that his services are needed by the entire ceramics industry. Consequently, it is unfair that any single firm take his entire services. It is the general feeling that some means should be found to maintain such experts where public rather than selfish interest is at stake.

Since this attitude of the ceramics manufacturers is diametrically opposed to the view expressed by a number of speakers and writers recently, it seems worth while to point out that in a broad way the stability of the government is involved in this particular question or in such questions as this incident raises.

It has been said that it is the function of the government to look after the welfare of its people; to protect the weak, and to guide the people as a whole.

In order that the Government may best serve the individuals in our democracy it is obvious that this can be most efficiently accomplished through the government's contact with the large organized units which have interests in common. In some phases our separate states represent interests common to large groups; similarly our cities represent certain interests of groups. In quite another way railroad transportation, meat packing, engineering societies, philanthropic societies, labor organizations, etc., all represent common interests of one kind or another. It always follows sooner or later that the common interests of groups conflict with the common interests of other groups, and it follows further that sooner or later it is necessary for the government to adjust differences that exist in these groups. If the government is to stand, it can only do so so long as it has an intelligent appreciation of the differences of the conflicting interests of major importance. Every technical as well as every legal, political, and economic organization of the country should see to it that the government has on its staff men who are in a position to understand and to assist. When this has finally been accomplished, all the big industries of our country and the large organizations generally, will be in a mood to proclaim the worthwhileness of a central government with ideals and courage to act.

After all, it is not surprising that the ceramics industry which involves the oldest of human arts, should have arrived at a mature philosophy such as its leaders have recently expressed.

ORIGINAL PAPERS AND DISCUSSIONS

CERTAIN RELATIONS BETWEEN CHEMICAL COMPOSITION AND REFRACTIVITY IN OPTICAL GLASSES[1,2]

By Fred. E. Wright

At the beginning of the war one of the serious problems which confronted the makers of optical glass in this country was the preparation of suitable "batches" for the types of optical glass required in military optical instruments. Before 1914 practically all of the raw optical glass used by American manufacturers was imported from Europe and little was known in this country of the processes of optical glass-making. This information had to be obtained quickly and put at once into practice if our field forces were to be adequately equipped with optical instruments for observational and measuring purposes.

In May, 1917, shortly after a group of men from the Geophysical Laboratory had been assigned, at the request of the Government, to the plant of the Bausch and Lomb Optical Company, Rochester, N. Y., to aid in the production of optical glass,

[1] Received Feb. 27, 1920.

[2] In the preparation of this paper a somewhat uncommon experiment was tried, namely, to present the major part of the subject-matter in graphical form. The written text is accordingly condensed and is an outline sketch rather than a comprehensive statement. The diagrams constitute the essential part of the paper and on them the emphasis has been placed. It is possible that this method of presentation is unsatisfactory; but by its adoption the length of the paper was greatly reduced and the methods actually used for attacking and developing a subject of this nature were thereby followed. The data (in particular the chemical data) which enter into the problem are in general not of a high order of precision and are therefore well adapted for study by graphical methods, especially as the practical problems are problems of interpolation and adjustment of different factors.

it was the writer's good fortune to deduce from the chemical and optical data then available certain relations which enabled us to write down the batch composition of any member of the flint series of glasses; also by graphical interpolation to cover most of the types of optical glass, including the barium crowns, borosilicate crowns, ordinary crowns, and the barium flints. This deduction had an important psychological effect because it rendered us independent of secret batches which had been obtained at great expense by empirical methods and were closely guarded; the new methods of attack gave us control over the whole series of batches. This one factor established, at the outset, our standing in the factory as practical glass-makers, and, as a result, secured for us hearty coöperation at a time when it was much needed.

The methods of computation are here presented in the incomplete form in which they were left at the close of the war. There is still much to be learned and much detailed information to be gathered before a comprehensive treatment of the subject can be attempted; but with the data now available it is a simple matter to reproduce any of the standard types of glass or of types intermediate between those listed in the glass-makers' catalogs.

Refractivity Relations in Optical Glasses

A fundamental requirement of optical glass is transparency and freedom from color; this means the absence of an absorption band in the visible spectrum; and this in turn sets a definite limitation to the possible variations in refractivity and greatly restricts the general character of the dispersion relations. With change in color (wave length of light) the refractive indices of optical glass change in the manner illustrated in figures 1*a* and 1*b* in which the refractive indices[1] of different kinds of optical glass are plotted for different wave lengths of light extending from the ultra-violet through the visible spectrum into the infra-red. The change in refractive index of a substance with change in wave length of light is called its optical dispersion. In an optical

[1] Measured by H. Rubens and T. H. Simon on a series of Schott glasses *Ann. d. Phys. u. Chem. N. F.*, **53**, 555 (1894).

glass the difference between the refractive indices for two given wave lengths of light is called its partial dispersion for that interval. Different types of optical glass are characterized not only by a difference in refringence for the same color, but also by different dispersion relations in the visible spectrum. These are of great importance to the lens designer.

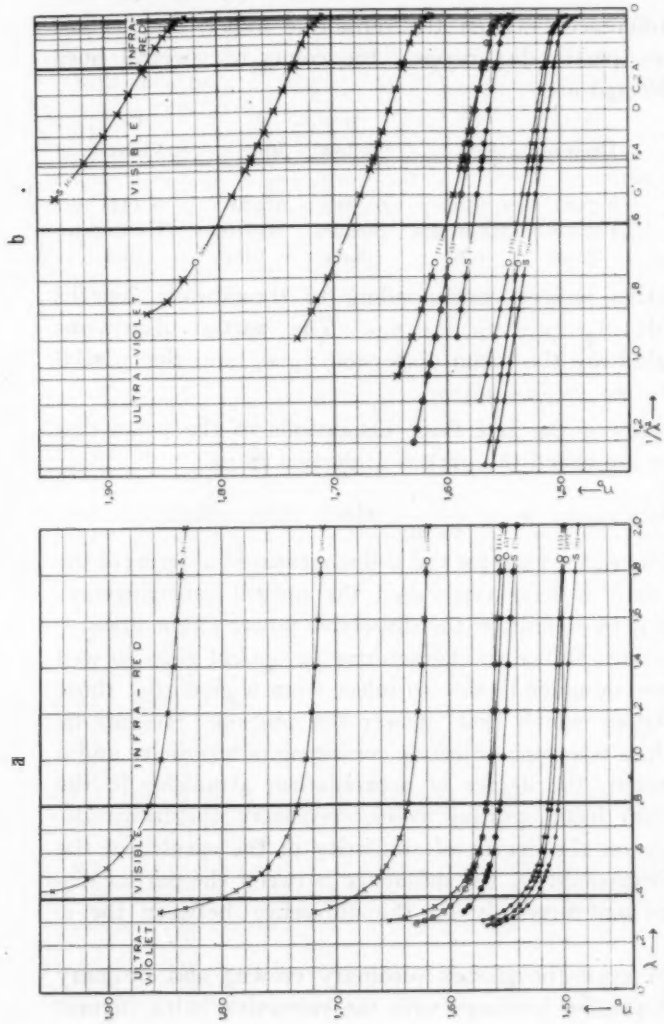


FIG. 1.—In Fig. 1*a* the refractive indices for different wave lengths in the infra-red, visible, and ultra-violet, as measured by H. Rubens and H. T. Simon on a series of Schott glasses, are plotted as ordinates against the wave lengths as abscissae.

In Fig. 1*b* the abscissae scale has been changed from the direct wave scale (λ) of Fig. 1*a* to that of the square of the frequency ($1/\lambda^2$). The refractive indices are the ordinates. By this method of plotting, the inflection point of the dispersion curves in the visible spectrum is clearly shown as a result of the absorption band in the ultra-violet and also in the infra-red.

In accord with the practice inaugurated by Abbe, the characteristics of an optical glass are stated by listing the following constants:

(*a*) Its refractive index for a definite color, generally that of the mean of the two sodium *D*-lines of average wave length, 0.5893 μ (microns or thousandths of a millimeter).

(*b*) The difference between the refractive indices for certain spectral colors (partial dispersions); the colors or spectral lines commonly selected are:

Spectral line	A′	C	D	F	G′
Color.....	Deep red	Red	Yellow	Blue	Violet
Wave length in microns (μ)....	0.7682	0.6563	0.5893	0.4861	0.4341
Source of light....	Potassium flame	Hydrogen tube	Sodium flame	Hydrogen tube	Hydrogen tube

The refractive indices corresponding to these wave lengths are expressed: $n_{A'}$, n_C, n_D, n_F, $n_{G'}$. The partial dispersions commonly listed are the mean dispersion $n_F - n_C$ and the partial dispersions $n_D - n_{A'}$, $n_F - n_D$, $n_{G'} - n_F$.

(*c*) The ratios of the last three dispersions to the mean dispersion; these are called the partial dispersion ratios.

(*d*) The expression $\nu = \frac{n_D - 1}{n_F - n_C}$ which is, in effect, the excess refractivity of the glass for the *D*-line measured in terms of the mean dispersion; it has been called the optical constringence; its reciprocal is by definition the dispersive power of the glass.

These constants suffice to characterize an optical glass so well that the optical designer is able to select from a given list those particular glasses which best answer his purpose. It can be proved that in a telescope objective consisting of a positive and a negative element, the degree of achromatism attainable in the image (freedom from spurious color, secondary spectrum) depends directly on the degree of similarity of the spectra of the two glasses (expressed by the difference between the partial dispersion ratios and inversely on the difference between the ν-values).

In the old types of glasses (ordinary crowns and ordinary flints) the dispersion increases with the refractive index (figures

1 and 2), but the dispersion in the blue end of the spectrum increases more rapidly than that in the red, and the spectra of

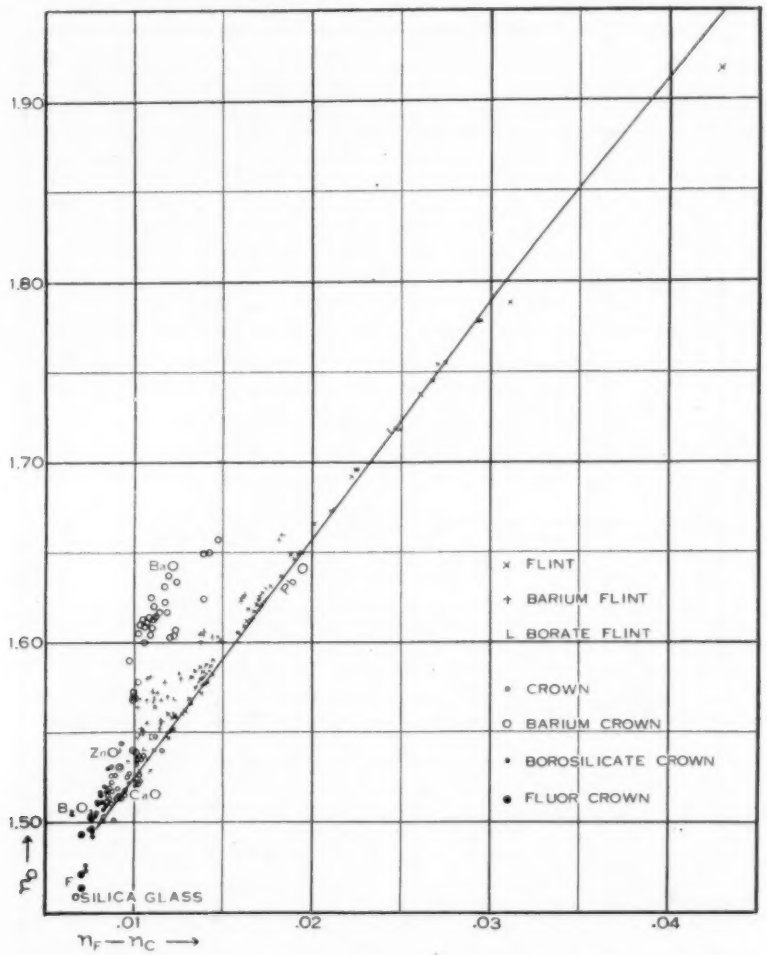


FIG. 2.—In this figure the mean dispersions of a series of glasses are plotted as ordinates, the refractive indices as abscissae. The old series of ordinary crown and flint glasses fall on a practically straight line.

different glasses are so dissimilar (irrationality of dispersions) that only a fair correction for achromatism can be attained.

The introduction of new types of glasses by Abbe and Schott enables the lens designer to produce much better lens systems than was formerly possible.

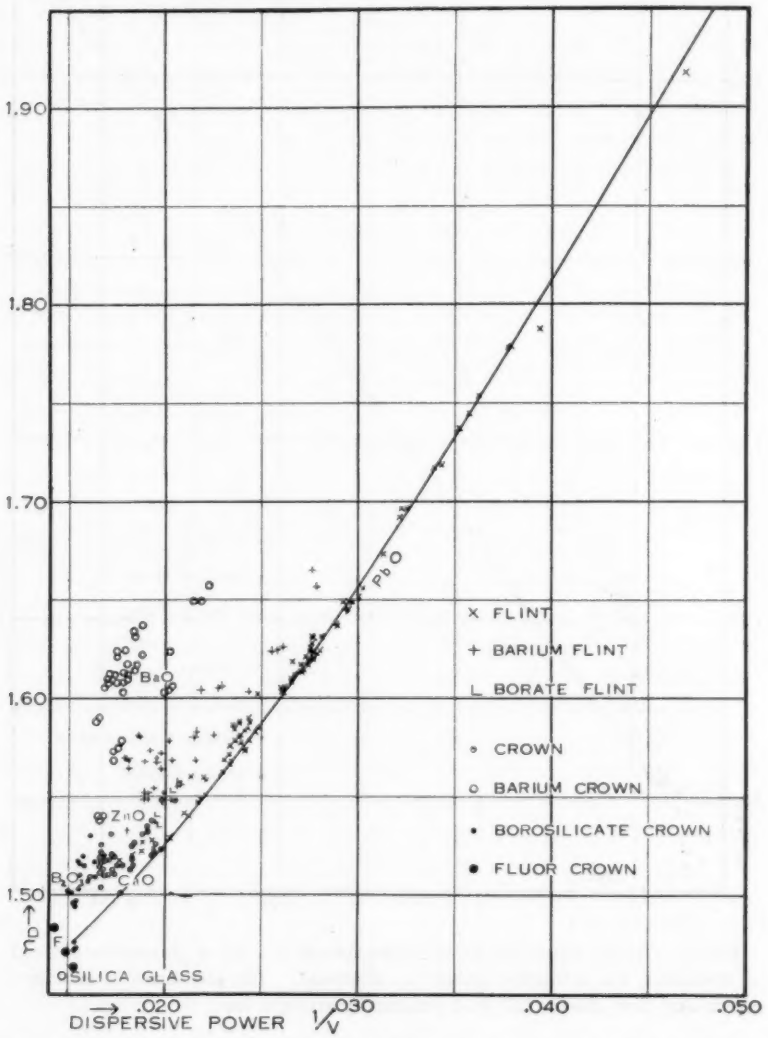


FIG. 3.—In this diagram the dispersive powers of a series of optical glasses are plotted against their refractive indices, n_D.

The different aspects of the refractivity relations of optical glasses are presented in figures 2 to 7. These will now be considered in some detail.

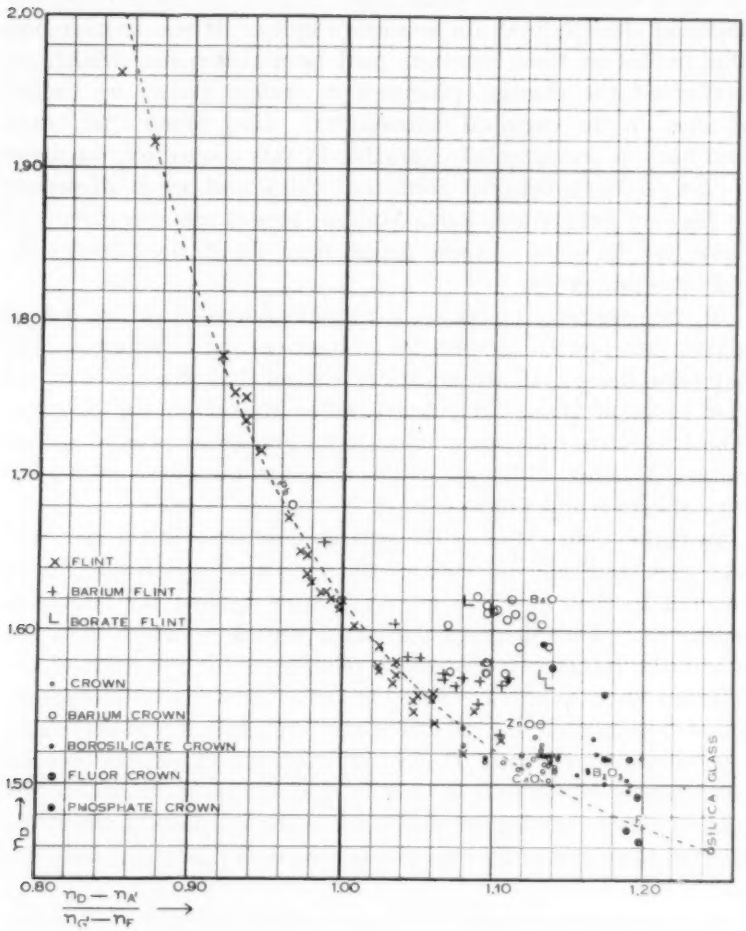


FIG. 4.—In this figure the ratio $\frac{n_D - n_{A'}}{n_{G'} - n_F}$, which expresses in effect the length of the red end of the spectrum relative to that of the blue end, is plotted against the refractive index n_D for a series of different types of silicate optical glasses.

It has long been known that if the mean dispersions of ordinary crown glasses and of flint glasses be plotted against refractive index, the points fall approximately on a straight line (figure 2). In other words, in these older types of glass the mean dispersion increases directly with the refractive index. It was to overcome this limitation that Harcourt, and later Abbe and Schott, investigated the changes produced in optical glasses by radical changes in the chemical composition. They found that boron and barium are especially valuable in this connection; in figure 2 the relations between refractive index and mean dispersion in the new Schott and Parra-Mantois glasses are also given and show how far some of these depart from the straight line of the old flints and crowns.

If the dispersive powers ($1/\nu$ as defined above) of the Schott glasses are plotted against the refractive index (figure 3), the old type glasses fall on a slightly curved line; the fields of the new types of glasses are clearly differentiated on the diagram. This is also true when the ν-values of the glasses are plotted against refractive index, although in this diagram the curve of the old type glasses is much more curved.

In figure 4 the ratios of the partial dispersions in the red ($n_D - n_{A'}$) and blue ($n_{G'} - n_F$) ends of the spectrum (relative length of the red to that of the blue) are plotted against the refractive index, n_D. This diagram illustrates probably better than the others the refractivity-dispersion relations; in it the fields of the different glass types are well marked. Thus in the fluor-crown glasses the length of the red end of the spectrum exceeds that of the blue end relatively more than in any other glass type; the borosilicate crowns follow next in order; then the ordinary crowns, the barium crowns, the barium flints, and finally the flints in which the relative dispersion of the blue ($n_{G'} - n_F$) exceeds that of the red ($n_D - n_{A'}$).

It is possible from figure 4 to select glasses differing appreciably in absolute refringence and at the same time to state their relative dispersions in the blue and red parts of the spectrum. Chemical analyses of many of the glasses plotted on this diagram are listed in table 3; by combining graphically the information presented in figure 4 and table 3, it is possible to deduce by interpolation

the approximate chemical compositions of glasses intermediate in optical properties between those which are plotted. The methods for accomplishing this are described in a later paragraph.

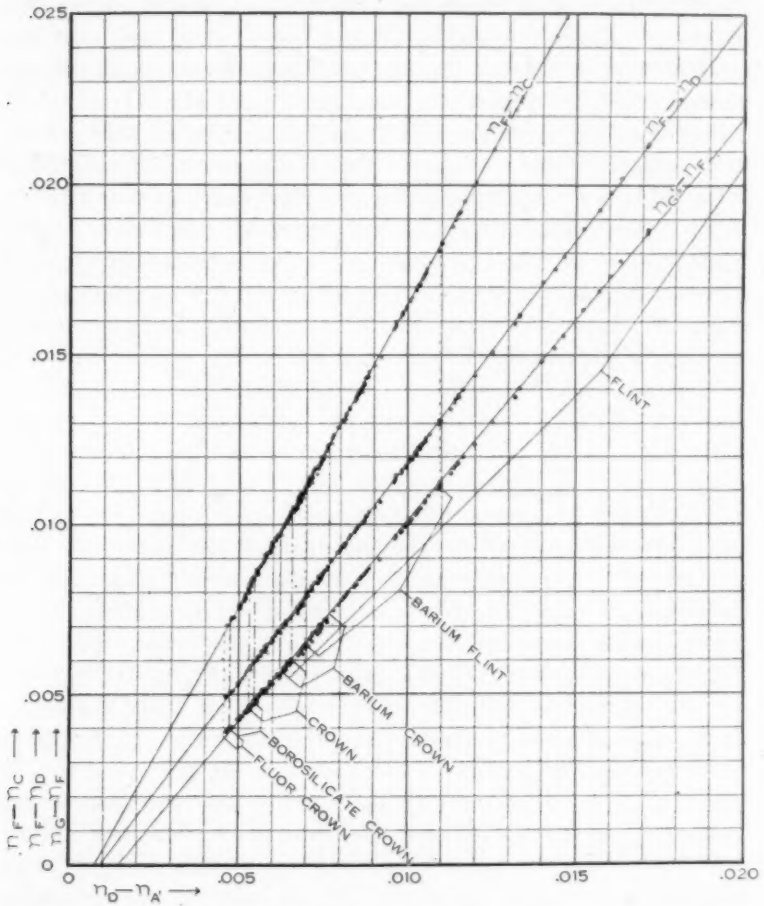


FIG. 5.—In this figure the partial dispersions, $n_F - n_C$, $n_F - n_D$, and $n_{G'} - n_F$, of all silicate optical glasses listed by Parra-Mantois and by Schott, are plotted as ordinates against the partial dispersion $n_D - n_{A'}$. The result in each case is an approximately straight line.

Figure 4 shows, moreover, the extent to which the glass-maker has succeeded in changing the refractivities of optical glasses.

The diagram includes the borate and phosphate glasses, in addition to the silicate glasses.

If now we consider only the partial dispersions and plot as in figure 5 the partial dispersion n_F-n_C, n_F-n_D, and $n_{G'}-n_F$ against $n_D-n_{A'}$ for a series of silicate glasses, the result in each case is a straight line; in figure 5 the partial dispersions of all the silicate glasses listed by Schott of Jena, and Parra-Mantois of Paris (about 289 different glasses in all) are included except those of the densest flint *S* 386 of Schott. This is a remarkable result and states that any partial dispersion of a glass bears a linear relation to any other partial dispersion; the degree of departure from this relation does not exceed one or two units in the fourth decimal place for the glasses plotted. Except for the dense barium crown glasses the distance of the points from the straight line is commonly only a few units in the fifth decimal place.

This fact, that in a series of optical glasses the partial dispersions are related by linear functions, proves that once a partial dispersion is given, the entire dispersion curve is fixed irrespective of the type of optical glass. This means that within the limits to which this statement holds, namely, about one unit in the fourth decimal place, if any partial dispersion is given, all other dispersions follow automatically; in other words, a change in dispersion at one part of the dispersion curve carries with it definite changes in the curve throughout the visible spectrum. Thus a series of standard dispersion curves can be set up independent of the absolute refractive index. This signifies that if, for any optical glass, two refractive indices be given, its dispersion curve can be written down directly; that in case two optical glasses of very different indices are found to have the same actual dispersion for one part of the spectrum, their dispersion curves are identical to one or two units in the fourth decimal place throughout the visible spectrum. If, for example, the refractive index, n_D, and the ν-value of an optical glass be given, its mean dispersion n_F-n_C can be computed from the equation $n_F-n_C = (n_D-1)/\nu$; its partial dispersions $n_D-n_{A'}$, n_F-n_D, and $n_{G'}-n_F$ can then be read off directly from figure 5 with a fair degree of accuracy, sufficient, at least, to give an adequate idea of the run of dispersion in the glass.

From these relations it is possible to build up dispersion formulas[1] containing two or three constants which represent the data in the visible spectrum with a high degree of exactness.

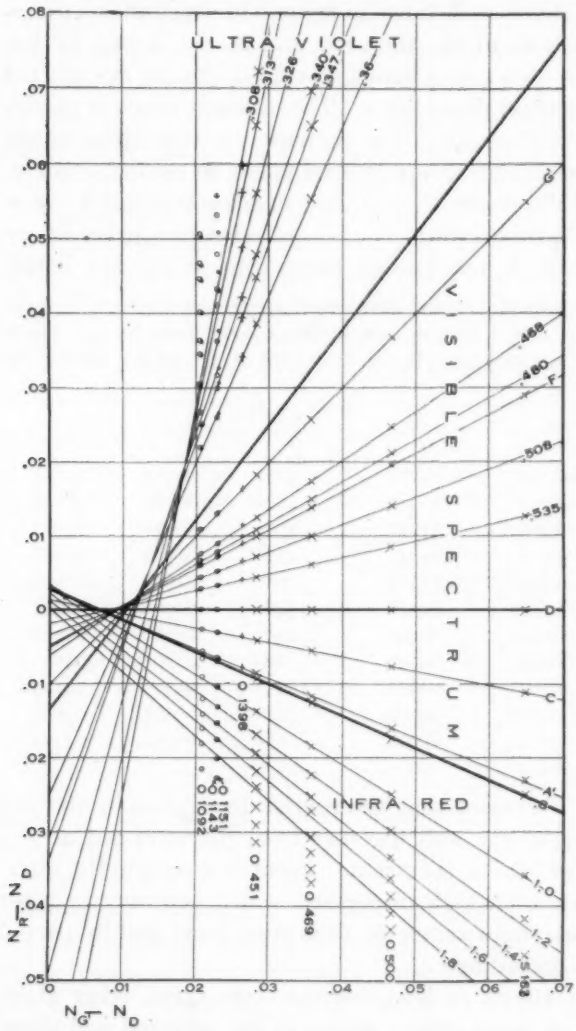


FIG. 6.—In this figure the partial dispersions $n_\gamma - n_D$ between the sodium line and the following wave lengths in μ, 2.4, 2.2, 2.0, 1.8, 1.6, 1.4, 1.2, 1.0, 0.8, 0.7682, 0.6563, 0.5892, 0.5349, 0.5086, 0.4861, 0.4800, 0.4678, 0.4340, 0.3610, 0.3466, 0.3403, 0.3261, 0.3133, 0.3081, 0.2980, 0.2880, 0.2837, 0.2763, are plotted as ordinates against the partial dispersions $n_G - n_D$ for a series of optical glasses measured by H. Rubens and H. T. Simon. The partial dispersions of the following Schott optical glasses are plotted on the diagram: O 1092, light barium crown (n_D = 1.51698); *S* 204, borate glass, (n_D = 1.51007); O 1143, dense barium crown, (n_D = 1.57422); O 1151, crown of high dispersion, (n_D = 1.52002); O 451, light flint (n_D = 1.57524); O 469, dense flint, (n_D = 1.64985); O 500, dense flint (n_D = 1.75130); *S* 163, extra dense flint, (n_D = 1.88995).

The linear relations between the partial dispersions of an optical glass are valid only for that portion of the dispersion curve

[1] F. E. Wright, *Journ. Opt. Soc. America*, **4**, 148–159 (1920).

which is distant from an absorption band. With the approach to an absorption band the dispersion curve departs from its even course and is no longer comparable with the dispersion curves of other glasses. This is well shown in figure 6 in which the measurements of H. Rubens in the infra-red and H. T. Simon[1] in the visible and ultra-violet in a series of optical glasses are plotted in terms of the partial dispersions. The different types of glasses are named on the diagram. The similarity in the course of the partial dispersions is well shown by two glasses in the list, namely, a crown of high dispersion *O* 1151, and of refractive index n_D = 1.52002, and a barium crown, *O* 1143, of refractive index n_D = 1.57422. In table 1 the partial dispersions $n_r - n_D$ are listed.

TABLE 1.—In this table the partial dispersions, $n_r - n_D$ of a crown of high dispersion, *O*1151, and a barium crown, *O*1143, are given for a series of wave lengths, *r*, extending from the infra-red at 2 μ to the ultra-violet at 0.2980 μ.

Wave length in μ r	*O*1151 $n_r - n_D$	*O*1143 $n_r - n_D$	Wave length in μ r	*O*1151 $n_r - n_D$	*O*1143 $n_r - n_D$
2.0	—0.02272	—0.02272	0.4861	0.00713	0.00704
1.8	— .02012	— .02012	.4800	.00780	.00766
1.6	— .01762	— .01772	.4678	.00901	.00884
1.4	— .01522	— .01542	.4340	.01310	.01288
1.2	— .01312	— .01312	.3610	.02664	.02500
1.0	— .01042	— .01312	.3466	.03066	.02977
0.8	— .00692	— .00692	.3403	.03260	.03161
0.7682	— .00634	— .00640	.3261	.03768	.03623
.6563	— .00290	— .00302	.3133	.04305	.04103
.5892	.00000	.00000	.3081	.04556	.04103
.5349	.00325	.00324	.2980	.05091	.04791
.5086	.00523	.00516	..	...	...

In this table it is evident that the partial dispersions of the two glasses run along fairly well together from the infra-red at 2 μ to the violet of the visible spectrum. From here on into the ultra-violet the crown with high dispersion, which contains 13.3 per cent of lead oxide, approaches an absorption band and its partial dispersions rise accordingly.

The different effects of lead, barium, boron and other glass-making oxides are more clearly shown in the infra-red and ultra-violet than in the visible spectrum. The maximal departure

[1] *Ann. Phys. u. Chem. N. F.*, **53**, 555 (1894).

from normal dispersion curves in the visible spectrum caused by the presence of large amounts of barium is two units in the fourth decimal place.

In the series of flint glasses an increase in lead oxide content raises the refractive index and causes the absorption band in the ultra-violet to shift toward the visible spectrum. This is clearly shown by the flint glasses plotted in figure 6, namely, *O* 451 (n_D = 1.57524), *O* 469 (n_D = 1.64985), *O* 500 (n_D = 1.75130), *S* 163 (n_D = 1.88995). Simon was unable, because of the presence of this absoprtion band, to measure the refractive indices of the light flint *O* 451 beyond the wave length 0.2980 μ, of the medium flint *O* 469 beyond 0.3261 μ, of the very dense flint *O* 500 beyond 0.3403 μ, and of the densest flint *S* 163 beyond 0.4340 μ. Further evidence of the shift of the absorption band with increase in lead oxide content has been obtained by the direct measurement of the transparency of the flint glasses to ultra-violet light. Data on the transmission of plates of flint and other optical glasses in the ultra-violet are given in the catalog of optical glasses issued by Chance Bros. The results of their measurements on the flint glasses are reproduced in table 2 in which the limit of trans-

TABLE 2.—Transparency of flint glasses in the ultra-violet

Type No.	Name	n_D	ν	Approximate percentage PbO	Wave lengths (μ) for transmission	
					50%	10%
7863	Extra light flint	1.5290	51.6	18	330	321
6953	Light flint	1.5412	47.6	23.5	316	313
572	Dense flint	1.6182	36.4	45	337	330
360	Dense flint	1.6225	36.0	46	338	332
337	Very dense flint	1.6469	33.7	51	347	341
4480	Very dense flint	1.7401	28.3	66	370	360

parency of a glass plate 1 centimeter thick is indicated by the wave lengths at which the percentage transmissions are 50 and 10, respectively.

With the exception of the first member of this series, which may contain an appreciable amount of zinc oxide that may affect the transparency in the ultra-violet, the absorption band is seen to shift continuously with increase in lead content toward the longer wave lengths and the visible spectrum.

The yellow color of the very dense flints has been ascribed to

the influence of this absorption band in reducing the intensity of the violet and blue of the visible spectrum; other factors, however, such as the presence, as impurities, of small amounts of iron oxide and possibly also of lead dioxide or other oxide of lead may have a pronounced influence on the color. Very dense flint glasses made of materials of high chemical purity and under conditions of thorough oxidation are noticeably less colored than glasses of the same composition whose batches and heat treatment have not been scrutinized carefully.

There are other approximately straight-line dispersion relations within the visible spectrum which may be noted because on them certain empirical dispersion formulas are based. Thus if the refractive indices be plotted as ordinates against the squares of the frequency ($1/\lambda^2$) as abscissae the course of the dispersion of an optical glass is represented by a curve which departs only slightly from a straight line (figure 1*b*); these departures are commonly less than one unit in the third decimal place.[1] A dispersion formula built up on this relation is the two-constant formula of Cauchy, namely,

$$n = A + B/\lambda^2$$

The formula may also be written

$$n - 1 = A' + B/\lambda^2$$

In view of the fact that the range of refractive indices in optical glasses over the visible spectrum is relatively limited, any approximately straight line relation between refractive index and a function of the wave length, such as expressed by the foregoing Cauchy formula, becomes an hyperbola if the reciprocal be taken of the refractive index or the excess refractivity; but the portion of the curve covered by the visible spectrum is so short that, even in this case, the departure of the hyperbola from a straight line is not great and the dispersion relations are still fairly well represented. Thus the new formula recently suggested by Nutting[2] is the Cauchy formula in which $\frac{1}{n-1}$ is written for n-1;

[1] See Sellmeier, *Ann. d. Phys. u. Chem.*, **143**, 272 (1871); also Pulfrich, *Ann. d. Phys. u. Chem.*, **45**, 648 (1892); and Hovestadt, Jenaer Glas, pp. 46–48, Jena, 1900.

[2] *Revisita d'Ottica e Meccanica di Precisione*, **1**, 54–57 (1919).

Nutting's formula represents the dispersions in certain cases better than the Cauchy formula, whereas in other glasses the Cauchy formula is the better. It would lead too far, in the present paper, to present data of computation on a series of Gifford glasses which bear out this statement. The conclusion is, however, directly evident from a comparison of figures 7*a* and 7*b* in which for all silicate glasses of Schott the squares of the frequency $(1/\lambda^2)$ are plotted as abscissae against $\frac{n-1}{n_A-1}$ and its reciprocal $\frac{n_A-1}{n-1}$ respectively, as ordinates. As a result of this method of plotting, all dispersion curves pass through the unit ordinate for the A′-spectrum line; the dispersion curves radiate from this point as approximately straight lines, the departures from straight lines being greatest in the dense flints and also in the very light crowns and borosilicate crowns.[1]

Another method of expressing the relations of the Nutting formula is to plot the frequency scale on the horizontal line at unit distance from the abscissa axis, to draw lines radiating from the origin through the points on the frequency scale and to find the intercepts of these lines with ordinates equal to the refractive indices.[2] The dispersion curves under these conditions are approximately straight lines.

These relations suffice to prove that in any dispersion formula (if carried only over the visible spectrum in a transparent colorless substance such as optical glass) which expresses the dispersion relations in approximately linear form, the reciprocals may be taken of the refractive index or any function of the same and the new dispersion curve thus obtained will again be approximately a straight line. In the ultra-violet and infra-red the relations may no longer obtain and inevitably break down as an absorption band is approached.

[1] Compare F. E. Wright, *Journ. Opt. Soc. America*, **4**, 195–204 (1920).

[2] For a brief account of this method of plotting reciprocals see F. E. Wright, *Jour. Wash. Acad. Sci.*, **10**, 185–188 (1920).

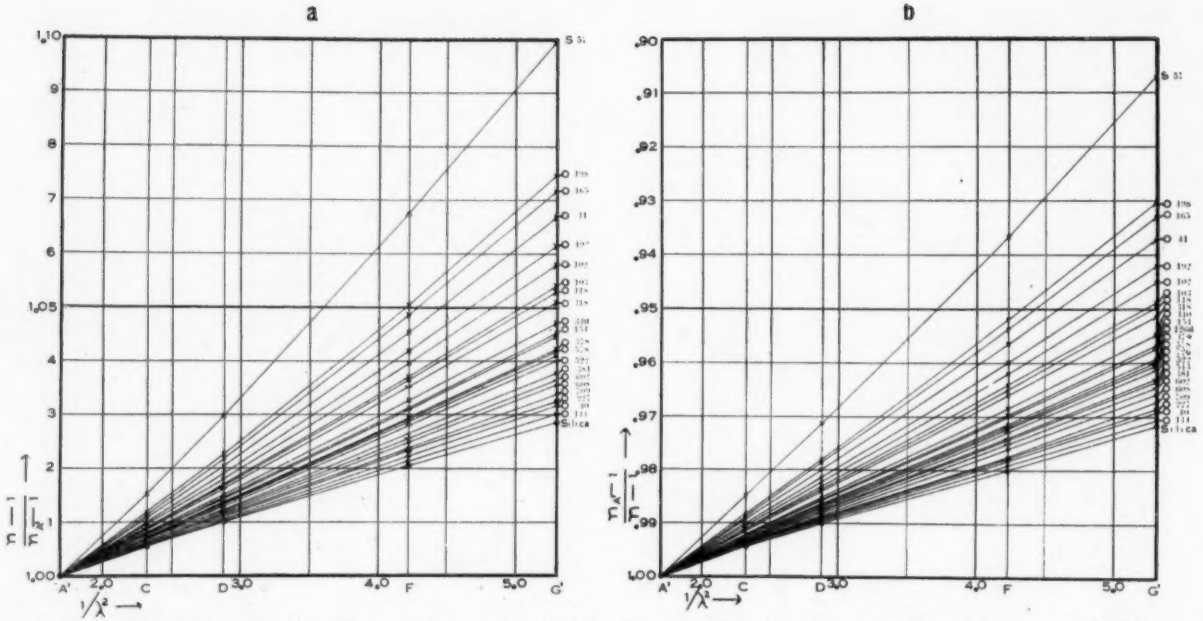


FIG. 7.—In Fig. 7*a* the ratios $(n_F-1)/(n_{A'}-1)$ for a series of Schott glasses are plotted as ordinates against the squares of the frequency $(1/\lambda^2)$ as abscissae. In Fig. 7*b* the reciprocal ratios $\frac{n_{A'}-1}{n_F-1}$ are plotted as ordinates against the same abscissae scale $(1/\lambda^2)$. The series of glasses represented in these figures are the same as those listed in Table 1 and include all types of silicate glasses. These figures demonstrate clearly the feasibility of substituting in the Cauchy dispersion formula $\frac{1}{n-1}$ for n-1 and thus obtaining the Nutting formula.

In figure 7*a* the excess refractivity $(n-1)$ for any wave length is expressed for each glass in terms of its excess refractivity for the A' wave length $(n_{A'}-1)$. The curves of this figure demonstrate that with rise in refractive index the dispersion also rises, and in the flint series especially the dispersion increases relatively faster than the refractive index. This fact of increased rate of rise of dispersion with increase in absolute refringence is also clearly shown by a comparison of the dispersion relations in the flint series of glasses, after reduction for each glass of all its refractive indices in the ratio n/n_D or $n/n_{A'}$. This procedure reduces the refractive index of each glass for the D-line to unity and thus renders the relations directly comparable. On plotting the ratios n/n_D against λ or $1/\lambda^2$ we find that in spite of the reduction of all glasses to a common datum level of absolute refringence $(n_D = 1)$, the higher the refringence in the flint glass series the greater the slope of the dispersion curve, thus proving the relatively greater dispersion of the heavy flint glasses.

The foregoing relations, together with other relations, such as are shown by graphical plots in which (*a*) $\frac{n_{G'}-n_F}{n_F-n_D}$ is plotted against $\frac{n_D-n_{A'}}{n_F-n_D}$; (*b*) $\frac{n_r}{n_D}$ against the wave length, λ_r, directly; (*c*) n_r against λ_r; (*d*) n_r against ν_r demonstrate that the actual shape of a dispersion curve in optical glasses can be changed only in a definite manner and that the departures from any one of the set of standard dispersion curves do not exceed two units in the fourth decimal place. The effort of the glass-maker is therefore necessarily directed toward the production of glasses of different refringences for the same general run of dispersions.

In the foregoing paragraphs the dispersion relations of optical glasses are presented on the diagrams in some detail and from different view points purposely, because they are of fundamental importance to the study of dispersion not only in optical glasses but also in other colorless substances. They indicate clearly the limits which the glass-maker has reached in his efforts to produce different types of optical glass and demonstrate that the paths which he may follow are narrowly prescribed.

Chemical Relations

The study of the refractivity relations in optical glasses as illustrated in the foregoing diagrams indicates that certain chemical oxides in combination with silica dominate certain fields. To determine these relations chemical analyses are essential; unfortunately the available analyses are not all of equal value. Table 3 contains the best chemical analyses at present known to

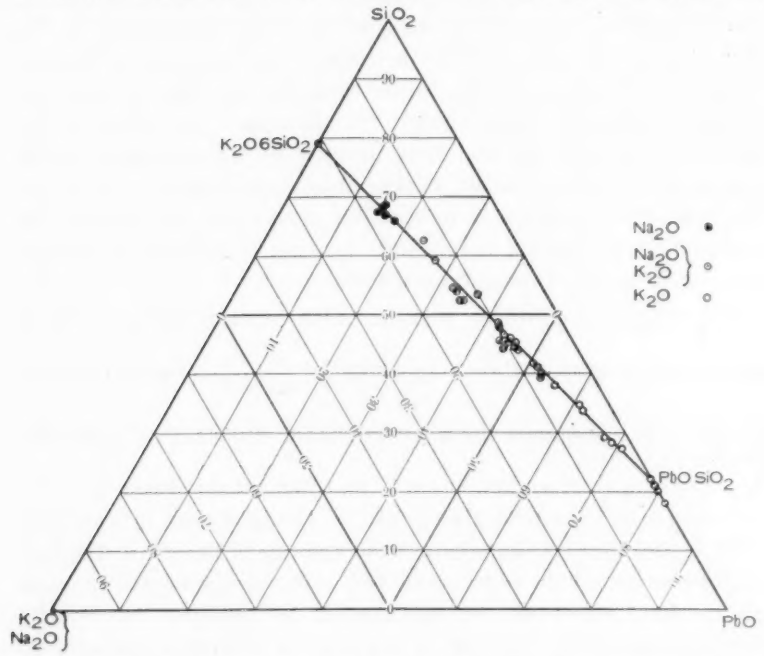


FIG. 8.—Triaxial diagram showing the weight percentage compositions of the potash flint and soda-potash flint glasses.

the writer.[1] Many of these "analyses" are synthetic compositions computed from the batch compositions; in the table the sum in each analysis of this type is either 100.0, or 99.9.

The simplest series of optical glasses is evidently the flint series and for this reason this series was studied first and certain com-

[1] See also list of analyses published by Williams and Rand. THIS JOUR., 2, 434–441 (1919).

TABLE 3.—Synthetic and actual chemical analyses of optical glasses of different types. In this table and accompanying legend are listed the chemical composition, the refractive index n_D, the ν-value, the density d, and the partial dispersions ($P.\ D.$) of the several glasses so far as these have been determined. The abbreviation Zsch. refers to the list of chemical analyses published by E. Zschimmer in Doelter's Handbuch der Mineralchemie, Vol. I, pp. 869–889 (1914). The abbreviation (W) refers to the list of glass analyses published first by Winkelmann in the *Ann. d. Phys. u. Chem.*, **49**, 401 (1893); **51**, 697, 730 (1894); **61**, 105 (1897); and later reproduced in Hovestadt's book on Jenaer Glas, Jena, 1900.

No.	SiO_2	B_2O_3	Al_2O_3	As_2O_3	PbO	ZnO	CaO	BaO	K_2O	Na_2O	Total	n_D	ν	d
						Ordinary Crowns								
1.....	74.6	...	..	0.3	...	...	5.0	...	11.0	9.0	100.0	1.5055	60.2	2.5
2.....	72.26	0.03	0.08	..	...	...	11.61	....	0.20	13.81	98.50	1.5261	59.3	..
3.....	71.34	....	.09	.90	...	...	12.51	...	.10	13.42	98.73	1.5250	59.1	..
4.....	70.6	...	..	.3	...	...	11.0	...	16.0	2.0	100.0	1.5179	60.2	2.49
5.....	71.6	...	..	.7	...	...	8.0	2.6	9.0	8.1	100.0	1.516	60.0	..
6.....	69.3	...	.3	.3	...	...	10.3	...	19.2	0.2	99.6	1.5176	60.1	..
						Borosilicate Crowns								
7.....	72.15	5.88	0.04	0.08	...	...	2.04	...	13.85	5.16	99.74	1.5102	64.1	2.47
8.....	70.4	7.5	..	.2	...	...	2.0	...	14.5	5.3	100.0	1.5100	64.0	2.47
9.....	70.0	8.0	..	.2	...	...	2.0	...	14.5	5.3	100.0	1.5118	63.5	2.47
10.....	70.0	8.3	..	.3	...	...	1.9	...	12.0	7.4	100.0	1.511	64.1	..
11.....	68.2	10.0	..	.2	...	...	2.0	...	9.5	10.0	100.0	1.5116	63.5	2.47
12.....	72.0	12.0	5.0	..	...	...	...	...	...	11.0	100.0	1.4997	64.7	2.37
13.....	71.0	14.0	5.0	..	...	...	...	...	...	10.0	100.0	1.4990	64.6	2.37
14.....	71.23	8.20	1.47	..	...	...	1.99	...	12.58	3.63	99.48	1.5140	63.1	...
15.....	70.6	6.0	1.0	.3	...	...	...	...	10.5	11.5	100.0	1.5069	62.3	2.48
16.....	70.95	6.30	0.88	.20	...	1.46	0.17	...	9.22	10.11	99.51	1.5079	62.1	...
17.....	69.58	9.91	.04	.09	...	...	.07	2.54	8.37	8.44	99.54	1.5164	64.0	...

Table 3 (continued)

Borosilicate Crowns (continued)

No.	SiO_2	B_2O_3	Al_2O_3	As_2O_3	PbO	ZnO	CaO	BaO	K_2O	Na_2O	Total	n_D	ν	d
18.....	69.0	2.5	..	.4	...	...	8.0	...	16.0	4.0	100.0	1.5168	60.9	2.49
19.....	68.5	3.5	..	.3	...	1.0	...	9.7	5.0	12.0	100.0	1.5183	60.4	2.63
20.....	68.1	3.5	..	.4	...	7.0	...	...	16.0	5.0	100.0	1.5107	60.5	2.5
21.....	67.73	9.98	.06	..	...	1.78	0.05	...	10.07	9.29	99.51	1.5142	64.0	..
22.....	65.6	4.5	..	.4	...	11.5	...	...	3.5	14.5	100.0	1.5175	60.2	2.59
23.....	65.5	2.5	..	.4	...	2.0	...	9.6	15.0	5.0	100.0	1.5170	60.4	2.49
24.....	64.6	2.7	..	.4	...	2.0	...	10.2	15.0	5.0	100.0	1.5179	60.2	2.58
25.....	53.5	20.0	..	..	...	...	...	...	6.5	...	100.0	1.5159	53.6	2.6
Zinc Silicate Crown														
26.....	71.0	...	...	...	...	12.0	...	...	...	17.0	100.0	1.5128	57.3	2.57
Barium Crowns														
27.....	59.5	3.0	..	0.3	...	5.0	...	19.2	10.0	3.0	100.0	1.5408	59.8	2.73
28.....	59.13	3.04	0.11	.34	...	5.00	0.13	19.25	9.70	3.16	99.88	1.5409	59.6	..
29.....	48.8	3.0	..	.4	...	10.3	...	29.0	7.5	1.0	100.0	1.5727	58.0	..
30.....	48.9	3.8	1.0	.3	...	8.9	...	28.6	4.3	4.3	100.0	1.570	57.0	..
31.....	48.2	3.7	1.0	.3	...	8.8	...	29.5	7.5	1.0	100.0	1.5724	57.6	3.21
32.....	48.1	4.5	..	.4	...	10.1	...	28.3	7.5	1.0	100.0	1.5726	57.5	3.21
33.....	47.8	4.5	..	.3	...	10.3	...	28.5	7.5	1.0	100.0	1.5742	57.2	3.21
34.....	47.73	3.90	0.65	.38	...	8.61	0.15	29.88	7.16	1.14	99.84	1.5726	57.4	..
35.....	46.9	4.5	..	.5	...	10.5	...	29.0	7.5	1.0	99.9	1.5748	56.9	3.21
36.....	48.8	3.0	..	.3	4.1	15.5	...	21.0	6.5	0.8	100.0	1.5791	53.6	3.26
37.....	45.02	4.50	0.09	.06	4.70	15.53	...	22.39	6.80	.64	100.18	1.5795	53.8	..
38.....	39.6	6.0	2.5	.5	...	9.2	...	42.1	...	...	100.0	1.6090	56.6	3.55
39.....	40.17	5.96	2.79	.03	...	8.17	0.03	42.35	0.03	0.13	100.17	1.6095	56.8	..

Table 3 (continued)

Barium Crowns (continued)

No.	SiO_2	B_2O_3	Al_2O_3	As_2O_3	PbO	ZnO	CaO	BaO	K_2O	Na_2O	Total	n_D	ν	d
40.....	37.5	15.0	5.0	1.5	...	...	...	41.0	...	...	100.0	1.5899	60.8	3.32
41.....	38.66	13.36	5.11	0.37	...	...	...	41.53	0.05	0.30	99.38	1.5904	61.3	..
42.....	37.3	6.0	2.0	..	...	10.8	...	40.5	...	3.2	99.8	1.6097	55.7	..
43.....	34.5	10.1	5.0	.5	...	7.8	...	42.0	...	...	100.0	1.6088	57.0	3.53
44.....	34.56	10.96	5.02	.04	...	1.14	...	46.91	0.09	0.21	99.48	1.6091	58.8	..
45.....	31.0	12.0	8.0	1.0	...	...	...	48.0	...	...	100.0	1.6098	58.8	3.54
						Flints								
46.....	69.2	...	..	0.3	6.5	...	4.0	...	17.0	3.0	100.0	1.5151	56.6	2.55
47.....	68.7	...	..	.2	13.3	2.0	...	...	...	15.7	100.0	1.5202	51.6	2.7
48.....	68.2	...	..	.2	13.1	2.0	...	...	...	16.5	100.0	1.5219	51.5	2.7
49.....	67.40	...	1.72	.14	10.71	3.85	0.39	...	0.14	15.13	99.69	1.5221	52.2	..
50.....	66.8	...	1.5	.2	11.6	3.8	...	...	...	16.0	100.0	1.5228	52.0	2.7
51.....	65.9	...	2.0	.2	16.3	...	...	...	...	15.5	99.9	1.5230	50.8	2.70
52.....	62.6	...	..	.3	24.1	...	...	...	8.5	4.5	100.0	1.5414	46.9	2.87
53.....	59.3	...	..	.2	27.5	...	...	...	8.0	5.0	100.0	1.5537	45.0	2.9
54.....	54.75	0.45	0.04	.06	29.30	0.96	0.05	1.64	7.99	4.31	99.97	1.5711	43.0	..
55.....	54.31	1.5	..	.2	33.0	...	...	...	8.0	3.0	100.0	1.5710	43.0	..
56.....	53.7	...	..	.3	36.6	...	...	...	8.3	1.0	100.0	1.5752	41.0	3.22
57.....	52.53	0.30	0.01	.13	34.42	0.03	0.04	...	8.21	3.78	99.72	1.5802	41.0	..
58.....	52.7	...	..	.4	35.0	...	...	...	5.5	6.3	100.0	1.580	41.1	..
59.....	48.7	...	..	.3	42.0	...	...	...	5.0	4.0	100.0	1.6054	37.9	3.5
60.....	47.9	...	..	0.3	42.4	...	...	...	5.1	4.3	100.0	1.605	37.6	..
61.....	46.6	...	..	.3	43.8	...	...	...	7.8	1.5	100.0	1.6137	36.9	3.58
62.....	46.12	...	0.06	.35	45.13	...	0.07	...	6.78	1.72	100.38	1.6163	36.6	..

Table 3 (continued)
Flints (continued)

No.	SiO_2	B_2O_3	Al_2O_3	As_2O_3	PbO	ZnO	CaO	BaO	K_2O	Na_2O	Total	nD	ν	d
63.....	46.32	...	.02	..	45.03	...	.25	...	5.63	2.48	99.82	1.6162	36.6	..
64.....	45.4	...	..	.3	45.1	...	...	...	7.7	1.5	100.0	1.6243	35.9	3.68
65.....	45.2	...	..	.2	46.0	...	...	...	7.5	1.0	100.0	1.6153	36.7	3.58
66.....	44.1	...	..	..	44.7	...	...	...	9.8	1.2	99.8	1.6188	36.2	3.6
67.....	47.6	...	..	.2	46.7	...	...	...	5.0	0.5	100.0	1.6129	36.9	3.58
68.....	45.64	...	0.03	.22	43.45	...	0.05	...	8.66	1.77	99.82	1.6137	36.9	..
69.....	45.2	...	.5	.2	46.4	...	...	...	7.5	0.2	100.0	1.6123	37.0	3.58
70.....	43.9	...	..	.2	47.3	...	...	...	8.0	.5	100.0	1.6130	37.0	3.58
71.....	44.6	...	..	.3	46.6	...	...	...	8.0	.5	100.0	1.6207	36.1	3.63
72.....	41.7	...	..	.3	50.5	...	...	...	7.0	.5	100.0	1.6485	33.8	3.87
73.....	41.7	...	..	.3	50.5	...	...	...	4.0	3.5	100.0	1.640	34.6	..
74.....	41.0	...	..	.2	51.7	...	...	...	7.0	...	100.0	1.6450	34.1	3.88
75.....	40.99	...	0.04	.22	51.13	...	0.13	...	6.93	0.61	100.15	1.6485	33.8	..
76.....	40.0	...	..	.3	52.6	...	...	...	6.5	.5	100.0	1.6500	33.6	3.87
77.....	39.2	...	..	.3	51.0	...	...	2.0	5.0	2.5	100.0	1.6657	32.9	4.1
78.....	38.0	...	..	.2	56.8	...	...	...	5.0	...	100.0	1.6801	31.7	4.1
79.....	34.7	...	..	.3	61.0	...	...	...	2.5	1.5	100.0	1.7172	29.5	4.49
80.....	33.7	...	..	.3	62.0	...	...	...	4.0	...	100.0	1.7174	29.5	4.49
81.....	29.3	...	..	.2	67.5	...	...	...	3.0	...	100.0	1.7510	27.6	4.73
82.....	28.4	...	..	.1	69.0	...	...	...	2.5	...	100.0	1.7541	27.5	4.78
83.....	27.3	...	..	.1	71.0	...	...	...	1.5	...	99.9	1.7782	26.5	4.99
84.....	22.0	...	..	..	78.0	...	...	...	...	...	100.0	1.8904	22.3	5.83
85.....	21.0	...	..	..	79.0	...	...	...	...	...	100.0	1.9068	21.6	..
86.....	20.0	...	..	..	80.0	...	...	...	...	...	100.0	1.9053	21.7	5.94
87.....	18.0	...	..	0.1	82.0	...	...	...	...	...	100.1	1.9626	19.7	6.33

Table 3 (continued)

No.	SiO_2	B_2O_3	Al_2O_3	As_2O_3	PbO	ZnO	CaO	BaO	K_2O	Na_2O	Total	n_D	ν	d
Borosilicate Flint														
88.....	29.0	29.0	10.0	..	30.0	...	...	...	0.5	1.5	100.0	1.5676	46.7	2.97
Barium Flint														
89.....	56.2	...	..	0.3	7.0	9.0	...	15.0	11.0	1.5	100.0	1.5500	53.3	3.0
90.....	55.9	...	..	.3	17.3	...	...	11.5	13.0	2.0	100.0	1.5560	48.6	3.03
91.....	53.5	...	..	.3	11.0	10.0	...	14.2	9.5	1.5	100.0	1.5630	50.8	3.11
92.....	51.6	...	..	.3	11.0	12.0	...	14.0	9.5	1.5	99.9	1.5637	50.6	3.11
93.....	51.7	...	..	.3	10.0	7.0	...	20.0	9.5	1.5	100.0	1.5718	50.4	3.19
94.....	50.2	...	..	.4	10.3	10.6	...	17.7	9.5	1.3	100.0	1.5745	50.2	3.2
95.....	51.2	...	..	.3	4.0	14.0	...	20.0	5.0	5.5	100.0	1.5692	52.9	3.12
96.....	50.2	...	..	.5	18.5	8.2	...	13.1	8.5	1.0	100.0	1.5832	46.3	3.29
97.....	49.80	...	0.05	.01	18.74	8.03	...	13.36	8.20	1.24	100.03	1.5832	46.3	..
98.....	49.1	...	..	.5	19.3	8.5	...	13.0	8.5	1.0	100.0	1.5822	46.3	3.29
99.....	45.2	...	..	.4	22.2	8.3	...	16.0	7.8	...	100.0	1.6042	43.9	3.50
100.....	45.2	...	..	.4	22.8	8.2	...	15.5	7.3	0.5	100.0	1.6026	44.2	3.40
101.....	43.8	...	..	.3	38.1	3.1	...	6.5	8.3	...	100.0	1.619	37.6	...
102.....	42.8	...	..	.5	32.6	5.1	...	10.8	7.5	0.7	100.0	1.6269	39.1	3.70
Borate Glasses														
103.....	...	69.1	..	18.0	0.2	...	...	4.7	...	8.0	100.0	1.5085	60.4	2.24
104.....	...	63.8	..	18.0	.2	3.0	...	3.5	3.5	8.0	100.0	1.5101	58.9	2.2
105.....	...	56.0	..	12.0	...	32.0	...	...	...	...	100.0	1.5734	46.9	3.0
106.....	...	49.7	..	13.0	0.3	37.0	...	...	...	...	100.0	1.6130	44.4	3.17
107.....	...	46.5	...	7.5	.2	46.0	...	...	...	...	100.0	1.6287	42.5	..
108.....	...	42.8	..	5.0	.2	52.0	...	...	...	...	100.0	1.6659	39.2	3.69

Table 3 (continued).

Borate Glasses (continued)

No.	SiO_2	B_2O_3	Al_2O_3	As_2O_3	PbO	ZnO	CaO	BaO	K_2O	Na_2O	Total	n_D	r	d
109.....	...	41.0	..	..	...	...	59.0	...	...	...	100.0	1.6525	50.8	3.53
110.....	...	71.8	..	22.4	...	...	...	...	...	...	100.0	1.5232	61.4	2.24
111.....	...	64.0	..	30.0	...	...	...	...	...	...	100.0	1.5194	60.9	2.21

Phosphate Glasses

112.....	...	3.0	70.5	10.0	0.5	...	...	...	12.0	...	100.0	1.5159	70.0	2.59
113.....	...	3.0	69.5	10.0	1.5	...	...	...	12.0	...	100.0	1.5215	69.7	2.59
114.....	...	3.0	59.5	8.0	1.5	...	...	28.0	...	...	100.0	1.5583	67.0	3.07
115.....	...	3.0	56.0	1.5	1.5	...	...	38.0	...	...	100.0	1.5670	65.6	3.24
116.....	...	3.0	54.0	1.5	1.5	...	...	40.0	...	...	100.0	1.5760	65.2	3.35
117.....	...	3.0	45.0	..	2.0	...	...	50.0	...	...	100.0	1.5906	64.1	3.66

LEGEND

Ordinary Crowns

1 Ordinary crown..... Zsch. 69 (W 91). With Mn_2O_3, 0.1.

2 Crown plate-glass..... Freden, Germany. E. T. Allen, analyst. With $Al_2O_3 + Fe_2O_3$, 0.08; Sb_2O_3, 0.51.

3 Crown plate-glass..... Pittsburgh Plate Glass Co. E. T. Allen, analyst. With $Al_2O_3 + Fe_2O_3$, 0.09.

4 Ordinary crown..... Zsch. 80. With Mn_2O_3, 0.1.

5 Light crown..... Spencer Lens Co. C. N. Fenner. *J. Am. Ceram. Soc.*, **2**, 143 (1919).

6 Hard crown..... Chance Bros. Zsch. 31. With $Al_2O_3 + Fe_2O_3$, 0.3. P. D.: $F\text{-}C = 0.00856$; $F\text{-}D = 0.00604$; $G'\text{-}F = 0.00484$.

Table 3 (continued)

Borosilicate Crowns

7	Borosilicate crown.....	Schott o 144. E. T. Allen, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Fe_2O_3, 0.1; As_2O_5, 0.20; H_2O, 0.08; SO_3, 0.12; Cl, 0.06.
7	Borosilicate crown.....	Schott o 144. Zsch. 137 (W 88). With Mn_2O_3, 0.1. P. D.: F-C = 0.00797; D-A' = 0.00519; F-D = 0.00559; G'-F = 0.00446.
9	Borosilicate crown.....	Schott o 144 (o 1948). Zsch. 138.
10	Borosilicate crown.....	Spencer Lens Co. C. N. Fenner. *J. Am. Ceram. Soc.*, **2**, 143 (1919).
11	Borosilicate crown.....	Schott o 144 (o 627). Zsch. 141. (W 49, 87). With Mn_2O_3, 0.1.
12	Borosilicate crown.....	Schott G 59 III. Zsch. 152. Thermometer glass.
13	Borosilicate crown.....	Schott o 802 (o 1450). Zsch. 153. (W 5). P. D.: F-C = 0.00765; D-A' = 0.00504; F-D = 0.00534; G'-F = 0.00423.
14	Borosilicate crown.....	National Opt. Co. E. T. Allen, analyst. With Fe_2O_3, 0.04; PbO, 0.12; MgO, 0.09; H_2O, 0.06; SO_3, 0.02; Cl, 0.05.
15	Borosilicate crown.....	Schott o 599. Zsch. 134. With Mn_2O_3, 0.1. P. D.: F-C = 0.00813; D-A' = 0.00529; F-D = 0.00569; G'-F = 0.00457.
16	Borosilicate crown.....	Schott o 599. E. T. Allen, analyst. With Al_2O_3 + Fe_2O_3, 0.88; H_2O, 0.16; SO_3, 0.06.
17	Borosilicate crown.....	Schott o 3832. E. T. Allen, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Fe_2O_3, 0.01; As_2O_5, 0.22; MgO, 0.07; H_2O, 0.06; SO_3, 0.08; Cl, 0.06. P. D.: F-C = 0.00806; D-A' = 0.00528; F-D = 0.00566; G'-F = 0.00448.
18	Borosilicate crown.....	Schott o 40 (o 55). Zsch. 136 (W 52, 89). With Mn_2O_3, 0.1. P. D.: F-C = 0.00849; D-A' = 0.00545; F-D = 0.00596; G'-F = 0.00479.
19	Borosilicate crown.....	Schott o 453 (o 4418). Zsch. 146. P. D.: F-C = 0.00860; D-A' = 0.00550; F-D = 0.00605; G'-F = 0.00486.
20	Borosilicate crown.....	Schott o 374 (o 662). Zsch. 139 (W 56). P. D.: F-C = 0.00844; D-A' = 0.00547; F-D = 0.00593; G'-F = 0.00479.

Table 3 (continued)

Borosilicate Crowns (continued)

21	Borosilicate crown.....	National Opt. Co. E. T. Allen, analyst. With Fe_2O_3, 0.05; Mn_2O_3, 0.03; MgO, 0.17; H_2O, 0.10; SO_3, 0.20.
22	Borosilicate crown.....	Schott o 546 (o 518). Zsch. 140. P. D.: F-C = 0.00859; D-A' = 0.00555; F-D = 0.00605; G'-F = 0.00485.
23	Borosilicate crown.....	Schott o 60 (o 122, o 1092). Zsch. 142 (W 60, 77). P. D.: F-C = 0.00853; D-A' = 0.00555; F-D = 0.00601; G'-F = 0.00489.
24	Borosilicate crown.....	Schott o 60. Zsch. 143 (W 28). P. D.: F-C = 0.00860; D-A' = 0.00553; F-D = 0.00605; G'-F = 0.00487.
25	Borosilicate crown.....	Schott o 608. Zsch. 131. With Sb_2O_3, 20.0. P. D.: F-C = 0.00943; D-A' = 0.00595; F-D = 0.00666; G'-F = 0.00543.

Zinc Silicate Crown

26	Zinc silicate crown.....	Schott o 709. Zsch. 16 (W 25, 79). P. D.: F-C = 0.00894; D-A' = 0.00575; F-D = 0.00630; G'-F = 0.00508.

Barium Crowns

27	Barium crown.....	Schott o 227 (o 3855). Zsch. 145. P. D.: F-C = 0.00909; D-A' = 0.00582; F-D = 0.00639; G'-F = 0.00514.
28	Barium crown.....	Schott o 227. E. Zies, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Fe_2O_3, 0.02.
29	Barium crown.....	Schott o 211 (o 885). Zsch. 144 (W 48).
30	Barium crown.....	Spencer Lens Co. C. N. Fenner. *J. Am. Ceram. Soc.*, **2**, 143 (1919).
31	Barium crown.....	Schott o 211 (o 4556). Zsch. 147.
32	Barium crown.....	Schott o 211. Zsch. 150 (W 85). With Mn_2O_3, 0.1. P. D.: F-C = 0.00995; D-A' = 0.00630; F-D = 0.00702; G'-F = 0.00588.

Table 3 (continued)

Barium Crowns (continued)

33	Barium crown.....	Schott o 211 (o 1143). Zsch. 149. With Mn_2O_3, 0.1. P. D.: *F-C* = 0.01006; *D-A'* = 0.00640; *F-D* = 0.00704; *G'-F* = 0.00584.
34	Barium crown.....	Schott o 211. E. T. Allen, analyst. With Fe_2O_3, 0.01; MgO, 0.02; H_2O, c.14; SO_3, 0.04; Cl, 0.03.
35	Barium crown.....	Schott o 211 (o 1580). Zsch. 148.
36	Barium crown.....	Schott o 722. Zsch. 133.
37	Barium crown.....	Schott o 722. E. Zies, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Al_2O_3 + Fe_2O_3 = 0.09; As_2O_5 = 0.55. P. D.: *F-C* = 0.01078; *D-A'* = 0.00681; *F-D* = 0.00761; *G'-F* = 0.00621.
38	Barium crown.....	Schott o 1209 (o 1922). Zsch. 151. With Mn_2O_3, 0.1.
39	Barium crown.....	Schott o 1209. E. T. Allen, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Fe_2O_3, 0.02; As_2O_5, 0.49. P. D.: *F-C* = 0.01068; *D-A'* = 0.00680; *F-D* = 0.00753; *G'-F* = 0.00610.
40	Barium crown.....	Schott o 2122. Zsch. 161. P. D.: *F-C* = 0.00970; *D-A'* = 0.00621; *F-D* = 0.00683; *G'-F* = 0.00546.
41	Barium crown.....	Schott o 2122. E. T. Allen, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Al_2O_3 + Fe_2O_3 = 5.11.
42	Barium crown.....	Mantois. Zsch. 127.
43	Barium crown.....	Schott o 1029 (o 1299). Zsch. 162 (W 15, 23). With Mn_2O_3, 0.1. P. D.: *F-C* = 0.01068; *D-A'* = 0.00680; *F-D* = 0.00753; *G'-F* = 0.00610.
44	Barium crown.....	Schott o 2071. E. T. Allen, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Al_2O_3, 5.02; As_2O_5, 0.55.
45	Barium crown.....	Schott o 2071. Zsch. 160. P. D.: *F-C* = 0.01037; *D-A'* = 0.00665; *F-D* = 0.00730; *G'-F* = 0.00590.

Table 3 (continued)

Flints

46	Crown of high dispersion...	Schott o 114. Zsch. 98. P. D.: F-C = 0.00910; D-A' = 0.00577; F-D = 0.00642; G'-F = 0.00521.
47	Flint.....	Schott o 381 (o 1151). Zsch. 30. With Mn_2O_3, 0.1. P. D.: F-C = 0.01026; D-A' = 0.00644; F-D = 0.00727; G'-F = 0.00596.
48	Flint.....	Schott o 381 (o 1168). Zsch. 29 (W 55).
49	Flint.....	Schott o 381. E. Posnjak, analyst. With Fe_2O_3, 0.02; Mn_2O_3, 0.04; H_2O, 0.15.
50	Flint.....	Schott o 381 (o 2074). Zsch. 27. With Mn_2O_3, 0.1.
51	Flint.....	Schott o 381 (o 1335). Zsch. 20.
52	Flint.....	Schott o 726 (o 3149). Zsch. 86. P. D.: F-C = 0.01142; D-A' = 0.00711; F-D = 0.00810; G'-F = 0.00669.
53	Flint.....	Schott o 378 (o 3807). Zsch. 88. P. D.: F-C = 0.01193; D-A' = 0.00739; F-D = 0.00847; G'-F = 0.00705.
54	Flint.....	Schott o 154. E. T. Allen, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Fe_2O_3, 0.02; As_2O_5, 0.14; H_2O, 0.20; Cl, 0.06. P. D.: F-C = 0.01327; D-A' = 0.00819; F-D = 0.00943; G'-F = 0.00791.
55	Flint.....	Schott o 154. Zsch. 89 (W 47). With Mn_2O_3, 0.1.
56	Flint.....	Schott o 569 (o 451). Zsch. 90. With Mn_2O_3, 0.1. P. D.: F-C = 0.01385; D-A' = 0.00853; F-D = 0.00987; G'-F = 0.00831.
57	Flint.....	Schott o 340. E. T. Allen, analyst. With Fe_2O_3, 0.02; H_2O, 0.09; SO_3, 0.10; Cl, 0.03. P. D.: F-C = 0.01396; D-A' = 0.00857; F-D = 0.00994; G'-F = 0.00837.
58	Flint.....	Spencer Lens Co. C. N. Fenner. *J. Am. Ceram. Soc.*, **2**, 143 (1919).
59	Flint.....	Schott 318 (o 4369). Zsch. 91. P. D.: F-C = 0.01575; D-A' = 0.00960; F-D = 0.01124; G'-F = 0.00952.
60	Flint.....	Spencer Lens Co. C. N. Fenner. *J. Am. Ceram. Soc.*, **2**, 143 (1919).

Table 3 (continued)

Flints (continued)

61	Flint	Schott o 118 (o 4271). Zsch. 92. P. D.: F-C = 0.01660; D-A' = 0.01006; F-D = 0.01184; G'-F = 0.01008.
62	Flint	Schott o 167. E. Zies, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Fe_2O_3, 0.02; H_2O, 0.03; SO_3, 0.10.
63	Flint	National Opt. Co. E. T. Allen, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Fe_2O_3, 0.03; H_2O, 0.06.
64	Flint	Schott o 93 (o 4237). Zsch. 94. P. D.: F-C = 0.01743; D-A' = 0.01053; F-D = 0.01243; G'-F = 0.01063.
65	Flint	Schott o 331. Zsch. 95. With Mn_2O_3, 0.1.
66	Flint	Mantois. Zsch. 93.
67	Flint	Schott o 118. Zsch. 50. P. D.: F-C = 0.01660; D-A' = 0.01006; F-D = 0.01184; G'-F = 0.01008.
68	Flint	Schott o 118. E. T. Allen, analyst. With $Al_2O_3 + Fe_2O_3$ = 0.03.
69	Flint	Schott o 118 (o 479). Zsch. 47 (W 46).
70	Flint	Schott o 118 (o 1469). Zsch. 52. With Mn_2O_3, 0.1.
71	Flint	Schott o 103 (o 2512). Zsch. 49. P. D.: F-C = 0.01709; D-A' = 0.01034; F-D = 0.01220; G'-F = 0.01041.
72	Flint	Schott o 102 (o 4591). Zsch. 53. P. D.: F-C = 0.01919; D-A' = 0.01152; F-D = 0.01372; G'-F = 0.01180.
73	Flint	Spencer Lens Co. C. N. Fenner. *J. Am. Ceram. Soc.*, **2**, 143 (1919).
74	Flint	Schott o 102 (o 1571). Zsch. 54 (W 26). With Mn_2O_3, 0.1.
75	Flint	Schott o 102. E. Posnjak, analyst. With Fe_2O_3, 0.02; H_2O, 0.08.
76	Flint	Schott o 102 (o 469). Zsch. 55. With Mn_2O_3, 0.1. P. D.: F-C = 0.01927; D-A' = 0.01161; F-D = 0.01382; G'-F = 0.01194.
77	Flint	Schott o 192 (o 3570). Zsch. 101.

Table 3 (continued)

Flints (continued)

78	Flint	Schott o 192. Zsch. 57. P. D.: F-C = 0.02104; D-A' = 0.01255; F-D = 0.01507; G'-F = 0.01302.
79	Flint	Schott o 41 (o 4113). Zsch. 96.
80	Flint	Schott o 41. Zsch. 58. P. D.: F-C = 0.02434; D-A' = 0.01439; F-D = 0.01749; G'-F = 0.01521.
81	Flint	Schott o 165 (o 500). Zsch. 59 (W 33). P. D.: F-C = 0.02723; D-A' = 0.01600; F-D = 0.01961; G'-F = 0.01709.
82	Flint	Schott o 165. Zsch. 60 (W 50). P. D.: F-C = 0.02743; D-A' = 0.01607; F-D = 0.01974; G'-F = 0.01730.
83	Flint	Schott o 198. Zsch. 61. P. D.: F-C = 0.02941; D-A' = 0.01719; F-D = 0.02120; G'-F = 0.01868.
84	Flint	Schott S 163. Zsch. 110 (W 18). P. D.: F-C = 0.03997; D-A' = 0.02293; F-D = 0.02895; G'-F = 0.02603.
85	Flint	Schott S 231. Zsch. 111 (W 64).
86	Flint	Schott S 208. Zsch. 112 (W 20).
87	Flint	Schott S 57. Zsch. 113. P. D.: F-C = 0.04882; D-A' = 0.02767; F-D = 0.03547; G'-F = 0.03252.

Borosilicate Flint

88	Borosilicate flint	Schott o 161. Zsch. 157. P. D.: F-C = 0.01216; D-A' = 0.00762; F-D = 0.00860; G'-F = 0.00709.

Barium Flint

89	Barium flint	Schott o 846 (o 3666). Zsch. 103. P. D.: F-C = 0.01042; D-A' = 0.00657; F-D = 0.00736; G'-F = 0.00602.

Table 3 (continued)

Barium Flint (continued)

90	Barium flint.....	Schott o 522 (o 3633). Zsch. 100. P. D.: F-C = 0.01153; D-A' = 0.00718; F-D = 0.00819; G'-F = 0.00677.
91	Barium flint.....	Schott o 543 (o 3868). Zsch. 106.
92	Barium flint.....	Schott o 543. Zsch. 107. P. D.: F-C = 0.01115; D-A' = 0.00699; F-D = 0.00790; G'-F = 0.00650.
93	Barium flint.....	Schott o 527. Zsch. 104. P. D.: F-C = 0.01133; D-A' = 0.00706; F-D = 0.00803; G'-F = 0.00660.
94	Barium flint.....	Schott o 527 (o 3187). Zsch. 105.
95	Barium flint.....	Schott o 602 (o 3524). Zsch. 102. P. D.: F-C = 0.01072; D-A' = 0.00675 F-D = 0.00759; G'-F = 0.00618.
96	Barium flint.....	Schott o 578 (o 4542). Zsch. 108.
97	Barium flint.....	Schott o 578. E. Posnjak, analyst. *J. Am. Ceram. Soc.*, **1**, 784 (1918). With Fe_2O_3, 0.01; As_2O_3, 0.51; H_2O, 0.08. P. D.: F-C = 0.01255; D-A' = 0.00777; F-D = 0.00891; G'-F = 0.00739.
98	Barium flint.....	Schott o 578 (o 1398). Zsch. 109. With Mn_2O_3, 0.1. P. D.: F-C = 0.1244; D-A' = 0.00774; F-D = 0.00896; G'-F = 0.00742.
99	Barium flint.....	Schott o 1266 (o 3111). Zsch. 64. With Mn_2O_3, 0.1. P. D.: F-C = 0.01381; D-A' = 0.0851; F-D = 0.00982; G'-F = 0.00821.
100	Barium flint.....	Schott o 1266 (o 1777). Zsch. 65. With Mn_2O_3, 0.1.
101	Barium flint.....	Spencer Lens Co. C. N. Fenner. *J. Am. Ceram. Soc.*, **2**, 146 (1919).
102	Barium flint.....	Schott o 748 (o 4534). Zsch. 66. P. D.: F-C = 0.01599; D-A' = 0.00965; F-D = 0.01142; G'-F = 0.00965.

Borate Glass

103	Borate glass.....	Schott S 196. Zsch. 171 (W 2).
104	Borate glass.....	Schott S 204. Zsch. 173.

Table 3 (continued)

Borate Glass (continued)

105	Borate glass.....	Schott V S 428. Zsch. 167 (W 42).
106	Borate glass.....	Schott S 4. Zsch. 168.
107	Borate glass.....	Schott S 99. Zsch. 169.
108	Borate glass.....	Schott S 120. Zsch. 170 (W 16).
109	Borate glass.....	Schott V S 665. Zsch. 164.
110	Borate glass.....	Schott S 185. Zsch. 165 (W 1). With Li_2O, 5.8.
111	Borate glass.....	Schott V S 458. Zsch. 166 (W 43). With Li_2O, 6.0.

Phosphate Glass

112	Phosphate glass.....	Schott o 225. Zsch. 179 (W 9, 57). With MgO, 4.0. P. D.: F-C = 0.00737; D-A' = 0.00485; F-D = 0.00515; G'-F = 0.00407.
113	Phosphate glass.....	Schott S 219. Zsch. 178 (W 27). With MgO, 4.0.
114	Phosphate glass.....	Schott S 206. Zsch. 177 (W 13).
115	Phosphate glass.....	Schott S 95. Zsch. 174 (W 14).
116	Phosphate glass.....	Schott S 30. Zsch. 175. P. D.: F-C = 0.00884; D-A' = 0.00570; F-D = 0.00622; G'-F = 0.00500.
117	Phosphate glass.....	Schott S 15. Zsch. 176. P. D.: F-C = 0.00922; D-A' = 0.00591; F-D = 0.00648; G'-F = 0.00521.

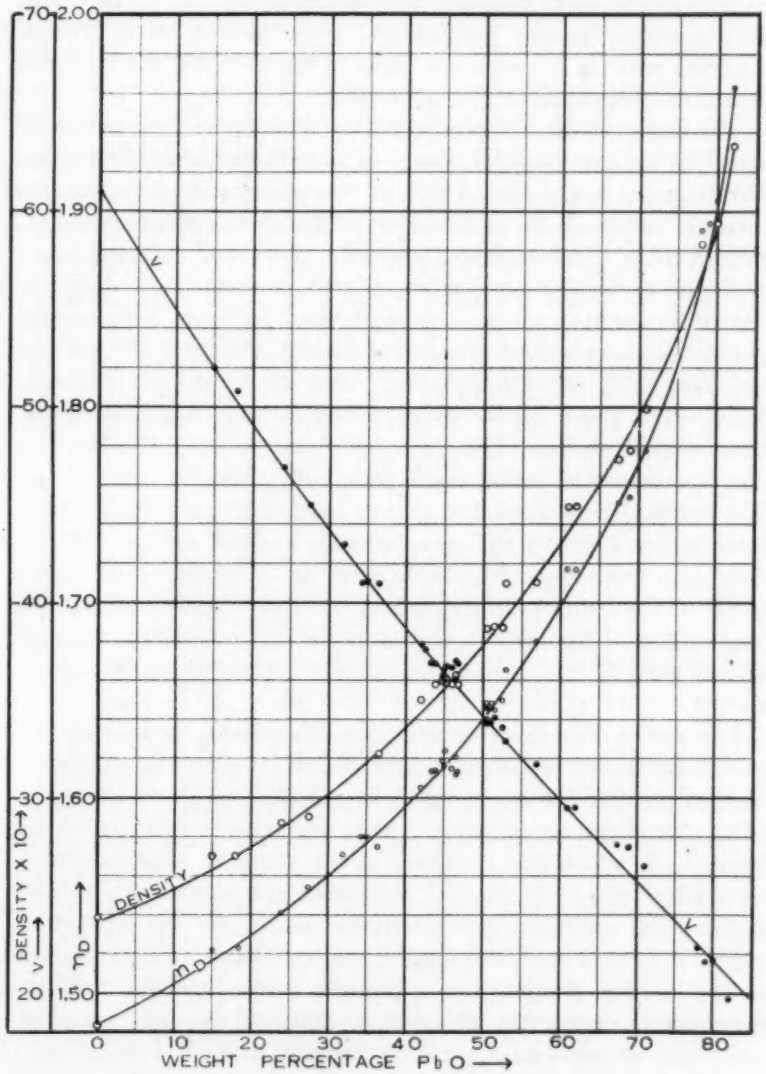


FIG. 9.—In this diagram are shown the changes in the density and the optical constants (refractive index n_D, and ν-value) with change in lead oxide (PbO) in the flint series of glasses.

position-refractivity relations were deduced from it. The chemical relations (weight percentages) were plotted on a triaxial diagram such as is commonly used in representing the relations in a three-component chemical system.

The fact that, for the members of the flint series, the refractivity relations are expressed by means of smooth continuous curves in the diagrams in the optical part of this paper, indicates that this series is analogous in its behavior, so far as the glasses are concerned, to a two-component system. If so, the chemical compositions of these glasses, when plotted in the triaxial diagram, should be found to fall on a straight line. In figure 8 the weight percentage compositions are plotted directly; the three components are silica (SiO_2), lead oxide (PbO), and the alkali oxides (Na_2O, K_2O). The points on the diagram include all available compositions of flint glasses. The potash flints are distinguished in the diagram from the soda-potash flints and from the soda flints. The compositions of all the glasses plotted fall practically on a straight line between the compositions: lead metasilicate ($PbO.SiO_2$) and the potassium silicate glass of the composition $K_2O.6SiO_2$, or the sodium silicate glass of the approximate composition $Na_2O.4SiO_2$. The optical constants of a synthetic potassium silicate glass of this composition were found to be: $n_D = 1.4836$; $\nu = 61.0$

The entire flint series is analogous chemically to a two-component mixture and, as such, any one of its physical constants, such as refractive index, ν-value, or density, varies continuously with change in composition. This variation is illustrated in figure 9, in which the variation in the chemical composition is represented along the abscissa axis as weight percentages of lead oxide. The ordinates give then the values of the refractive index for sodium light, the ν-value, and the density for the glasses of the several compositions. Smooth curves passing through these points enable the observer to read off the percentage of lead oxide required in a glass having any desired constant represented on these curves. In figure 10 the changes in other optical constants (partial dispersions, ν-value) as well as in lead oxide content, with change in refractive index n_D, are represented for all Schott and Chance flint and ordinary crown glasses. These

changes are represented in the flint series by smooth continuous curves. The diagram shows that the flint glasses are characterized by higher dispersions and a more rapid relative rise in dispersion

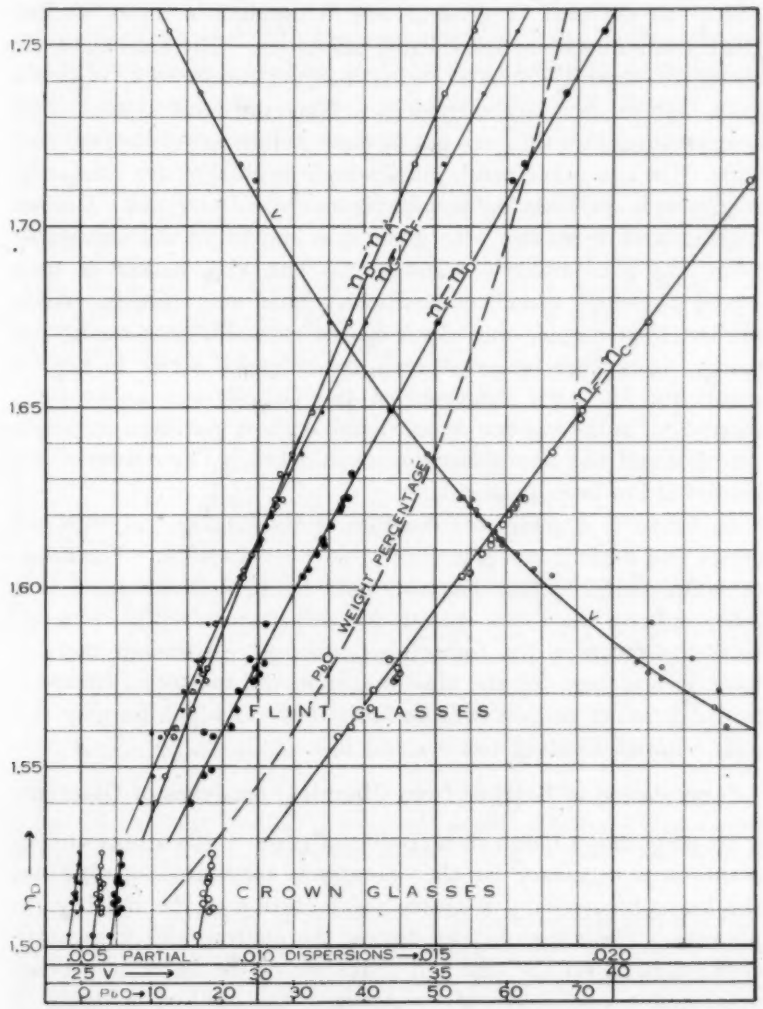


FIG. 10.—In this diagram the changes in partial dispersions, partial dispersion ratio, ν-values, density, and in lead content with change in refractive index are shown.

with rise in refractive index than is the case in the ordinary crown glasses.

The foregoing three figures represent the sum total of empirical efforts on the part of glass-makers to produce a series of flint glasses which have certain optical properties. The reason for the straight composition-line of figure 8 is not far to seek. Glasses very high in silica are extremely viscous and melt at such high temperatures that they can not be made in furnaces of the ordinary type. On the other hand, glasses high in alkalies are extremely hygroscopic and therefore unsuitable for optical purposes. Glasses high in lead crystallize with great ease and hence are unsuitable from the glass-maker's standpoint. The glass-maker is thus forced to adopt those compositions which melt readily, which are not hygroscopic, and which do not crystallize too readily on cooling from high temperatures. An extended series of experiments by Mr. Olaf Andersen of the Geophysical Laboratory, carried out in the laboratory on a small scale in platinum crucibles, corroborated the above conclusions in detail. The results of his studies are to be published later.

In figure 11 a composite diagram of the relations in both the crown and flint silicate glasses of table 3 is presented. The range of compositions in this diagram, as in figure 8, is restricted to a fairly definite band; the reasons for this narrow belt of compositions are given in the foregoing paragraph. Although there is more leeway here for the glass-maker in the matter of compositions, there are certain definite limits beyond which he may not pass without inviting trouble and loss.

Computation of Batches from Chemical Analyses of Glasses

In preparing a batch to reproduce a glass of given optical constants it is necessary for the operator to take into consideration the losses incurred by selective volatilization of the batch components. The amounts lost during the melting and fining processes depend on the size and character of the batch, the character and temperatures of the furnace, the method of filling in the batch, the type of the melting pot, whether open, semi-closed, or closed, the duration of the operations, and the character of the stirring, so that it is not possible to give more than rough per-

centage estimates of these factors. A few experiments suffice, however, to determine the relations for a given set of operating conditions; once these have been ascertained the glass-maker endeavors to adhere to them strictly and thus to insure uniformity in the final product. In the computation of the batch mixtures the following allowances are made for losses by selective volatilization: PbO or Pb_3O_4 0.5 to 5 per cent, and even higher;[1] boric

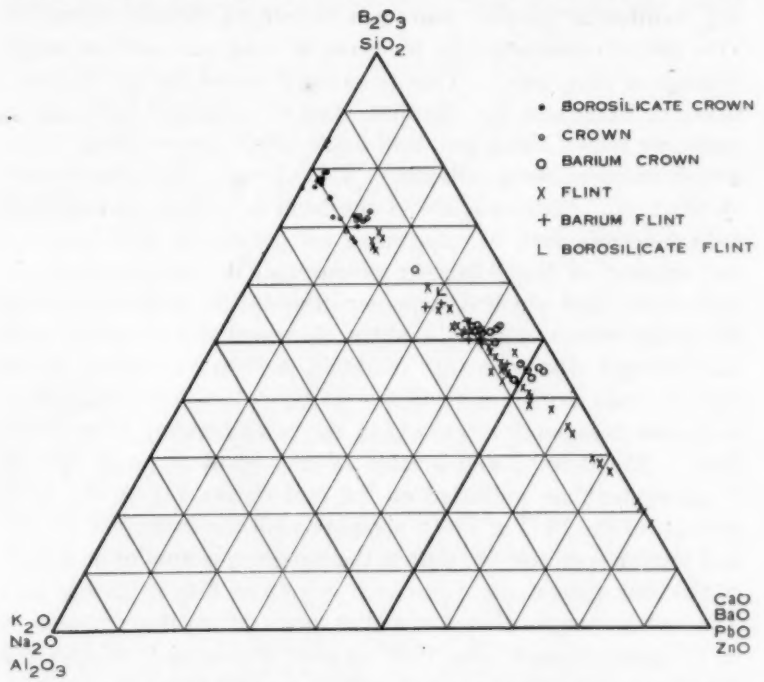


FIG. 11.—Triaxial diagram showing the weight percentage compositions of the ordinary crowns, borosilicate crowns, barium crowns, flints, barium flints, and borosilicate flints of Table 3.

oxide 1 to 5 per cent in case boric acid rather than borax is used in the batch; the alkalies, K_2O and Na_2O, up to 5 per cent. Little definite information is available on the losses incurred by selective volatilization and in a given case much depends on the factors

[1] See Olaf Andersen. The volatilization of lead oxide from lead silicate melts, *J. Am. Ceram. Soc.*, **2**, 784 (1919).

already mentioned. At the present time it is a matter largely of experience and of actual trial to make proper allowance for these factors. As a result of this volatilization the batch becomes relatively richer in silica and the refractive index of the finished glass is lowered.

From the relations presented in foregoing paragraphs it is possible to prepare a plot from which the batch composition for any member of the flint series can be read off directly (figure 12). This plot is constructed on the basis of sand 100 units of weight (pounds or kilograms). Thus from the diagram the batch composition in kilograms for the flint glass of refractive index n_D = 1.640, we read: Sand 100, lead oxide (PbO) 119 or (Pb_3O_4) 122; anhydrous potassium carbonate (K_2CO_3) 20.6; potassium nitrate (KNO_3) 7.0. Sodium oxide in the form of sodium carbonate or sodium nitrate may be substituted for potassium oxide provided the amount of Na_2O (weight percentage) equals in weight the amount of K_2O which it replaces; substitution of Na_2O for K_2O raises the refractive index slightly, decreases the ν-value slightly and changes the viscosity relations noticeably. Flint glasses high in soda exhibit a tendency to be duller, less transparent, and more noticeably colored than the corresponding pure potash flints. The density and ν-value of any glass of given PbO or Pb_3O_4-content are indicated on the plot (figure 12) by the intersections of the PbO or Pb_3O_4 ordinate with the curves for density and ν-value respectively; thus in the foregoing example the density of the flint glass n_D = 1.640 is d = 3.78 and its ν-value is 34.5. The batch composition for a flint glass of ν-value = 46.0 is, in kilograms : sand 100; PbO 44.5 or Pb_3O_4 45.5; K_2CO_3 7.6; KNO_3 2.2. Its density is 2.93 and its n_D = 1.549.

The compositions of glasses of other types can be ascertained by means of the compositions given in table 3, together with the data plotted especially on figures 4 and 11. It would lead too far in the present paper to consider these systems in detail; in some of them the information at hand is meager and hardly sufficient for satisfactory interpolation; but in most instances the glass-maker, with the aid of these methods and the data now available, is able to write down batches which approach very closely the batch desired, so that with a few experimental melts

in small crucibles he can determine the correct batch composition within very narrow limits.

The foregoing diagrams indicate clearly the fields which are dominated by the different oxides; in view of these relations it is, therefore, fitting to name the silicate glasses as has been done: fluor crowns, borosilicate crowns, ordinary crowns, and barium crowns; flints, barium flints, and borosilicate flints. Zinc-bearing g'asses do not require separate designation because zinc oxide

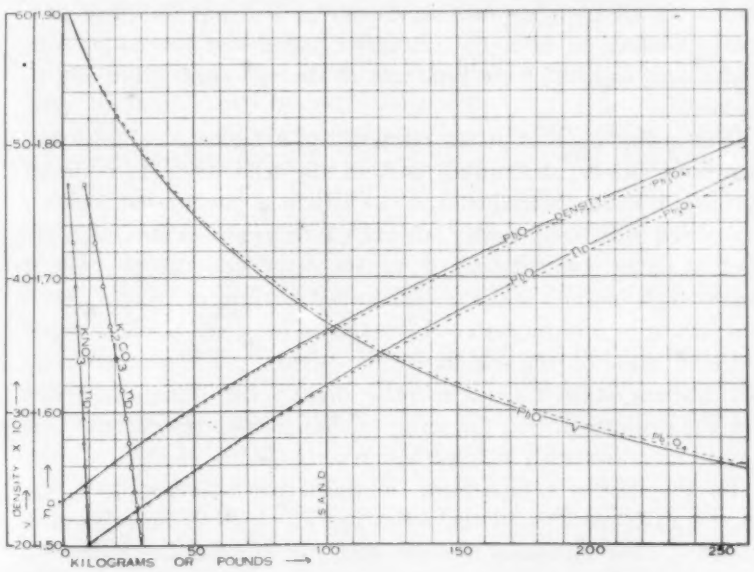


FIG. 12.—Batch composition diagram for the series of optical flint glasses.

in optical glasses does not impart special optical properties to the glass; it serves chiefly to change the concentration and viscosity relations in optical glass melts, especially to render the melt easier to work and to decrease the tendency to crystallize on cooling. In the flint series the light, medium, and dense flints are distinguished. The barium flints are flints in which part of the lead is replaced by barium. In all types of silicate glasses the amount of silica present is relatively large and the optical characteristics

of each glass are in effect a blend of characteristics between those of silica and some other end member or members, with silica commonly dominating.

A study of the above diagrams, especially figure 4, proves that in the silicate optical glasses, lead and barium oxides on the one hand, silica and boron oxide on the other, exert the most profound influence on the optical constants of the glass. Thus the highly refracting glasses contain abundant lead oxide or barium oxide; the low refracting glasses contain abundant silica or boron oxide. Of all the glass-making elements, lead has the most pronounced effect on both the refractive index and the dispersion; it increases especially the blue end of the spectrum relatively to the red.

If in a flint glass of given refractivity, a higher ν-value (lower dispersive power) is desired, part of the lead oxide is replaced by barium oxide (introduced in the batch as barium carbonate). Compared with lead oxide, barium oxide produces less high refractive index and very much weaker dispersion (high ν-value); glasses high in BaO and PbO are called barium or baryta flints. Zinc oxide is intermediate in its action between calcium oxide and lead oxide on the one hand, and barium oxide on the other; like calcium oxide it tends to raise slightly the refractive index and the dispersion. In the series of flint glasses the relative dispersion increases with increase in refractive index; in other words, if, for the sake of comparison, the refractive indices $n_{A'}$, n_C, n_F, $n_{G'}$, for each member of the series are divided by the refractive index n_D, then the ratios increase with rise in refractive index n_D the characteristic feature of the dispersion of lead glasses is the rapid rise in refractivity toward the blue and violet end of the spectrum. The same relations are clearly shown in a diagram in which the ratios $\frac{n_D - n_{A'}}{n_F - n_D}$ and $\frac{n_{G'} - n_F}{n_F - n_D}$ are plotted as abscissae against the refractive index as ordinates.

Increase in silica, boron oxide, or fluorine tends, on the other hand, to lower the refractive index, to increase relatively the dispersion of the red end of the spectrum and at the same time to decrease the total dispersion. This lengthening of the red end

of the spectrum is especially true of boron oxide and of fluorine.[1]

The addition or substitution of small amounts of boron oxide slightly raises the refractive index of certain glasses. This behavior is remarkable because by itself the refractive index of boric oxide glass is only $n_D = 1.463$ and the ν-value 59.4; that of silica glass is $n_D = 1.4585$ and the ν-value 67.9. Evidently borates are formed which impart different properties to the glass from those which might be inferred from the characteristics of the individual components.[2] Similarly alumina (Al_2O_3), which in the crystallized state has a very high refractive index (1.76), produces with silica a glass of unexpectedly low refractivity. Alumina and magnesia raise the viscosity of most glass melts and tend thereby to prevent crystallization.

Phosphorus, although formerly used in appreciable amounts, especially in the series of phosphate glasses, has now been discarded because of the poor weather-resistant qualities of the phosphate glasses. Figure 4 shows that these glasses differ only slightly from the borosilicates and the barium crowns; this difference does not outweigh the practical disadvantage of weathering instability.

The essential differences between the ordinary flints and ordinary crowns are the higher refractivity and the greater dispersion, both actual and relative, in the flint glasses, especially in the blue end of the spectrum. With these two types of glasses it is not possible therefore to compensate exactly the dispersive effects of a positive crown element by a negative flint element and secondary spectrum results. By the use of glasses in which the relative dispersions are more nearly similar than between the crowns and flints, it is possible to correct more perfectly for achromatism; the presence of the two chemical elements, barium and boron, in optical glass shifts the relative dispersions in the crowns and flints so that they are more nearly in accord. By the use of these elements in the flint glasses the extreme dispersions

[1] The statement made by Hovestadt, Jenaer Glas, p. 11, 1900, that boron oxide tends to lengthen the red end of the spectrum, whereas fluorine has the opposite effect and tends to decrease the red end relatively to the blue, is not borne out by the fluor-crown glasses.

[2] See also Zschimmer, Zeitschr. Elektrochemie, **11**, 632, 1905.

of the blue end of the spectrum in the normal flint glasses are reduced relatively and the course of the dispersion throughout the visible spectrum is rendered more nearly like that of a crown glass.

In writing down the batch for a glass of specified refractive index and dispersion the glass-maker has a number of factors to consider, such as chemical composition, and the changes in composition resulting from selective volatilization and from pot solution. In the series of ordinary crowns and flints, silica (sand), alkalies (potassium and sodium oxides), lime (calcium oxide), and lead oxide are the essential constituents; in these the proportions of the different elements may not exceed certain limits. If the percentage of silica is above 75 per cent the melt is so viscous that it can not be properly melted in the furnace; the percentage of alkalies may not exceed 20 per cent, otherwise the resultant glass is hygroscopic and chemically unstable; over 13 per cent of lime may not be used because of the tendency of melts high in lime to crystallize, and because of the difficulty of fusing such melts properly; lead oxide may be used up to 70 per cent or more, but in glasses containing a large percentage of lead the danger from crystallization and from attack on the melting pot is serious. In the new series of glasses, boron, barium, zinc, and aluminum oxides are the most important additional constituents which are employed; up to 50 per cent barium oxide may be used, but then ordinarily together with boron and alumina; melts high in barium attack the crucible seriously, especially if any free silica is present in the clay. The dense barium glass melts require, moreover, special furnace treatment to produce a glass free from bubbles and other defects such as crystallization nuclei.[1] Boron oxide may be used up to 20 per cent or more; it replaces, in a measure, silica. In general the use of small quantities of boric acid in lead glasses is not to be recommended because experience has shown that its presence favors the development of opalescence in the glass on cooling. Zinc in quantities above 12 per cent is likely to cause crystallization of the glass. More than 5 per cent of

[1] Compare N. L. Bowen, *J. Wash. Acad. Sci.*, **8**, 265–268 (1918); *J. Am. Ceram. Soc.*, **2**, 261–281 (1919).

alumina tends to render certain glass melts exceedingly viscous and practically unworkable at the melting temperatures; the presence of alumina decreases the danger from crystallization and renders the glass tough and resistant. In the densest barium crown glasses up to 10 per cent Al_2O_3 may be used; it aids not only in preventing crystallization of barium disilicate, but it also improves the working qualities of the melt and glass. The presence of chlorine or sulphur in the batch materials is to be avoided because of the danger of opalescence in the finished glass. In case these elements are present, it is advisable to run the melt at a very high temperature.[1]

The presence of arsenic in most glasses is favored by most glass-makers because it tends to increase the transparency and brilliancy of the glasses; certain experiments indicate that the presence of arsenic in the melt probably sets up an oxidizing action at high temperatures[2] and thus reduces the effect of iron as a coloring agent. Although some arsenic is volatilized in the melt, an appreciable amount remains in the solution. Careful analytical work by Allen and Zies[3] of the Geophysical Laboratory has demonstrated the presence in optical glasses of arsenic in both states of oxidation, as arsenic trioxide and arsenic pentoxide.

In the preparation of batches the nitrates and carbonates of the alkalies are used in proportions ranging from 1 : 5 to 1 : 2, depending on the type of glass; nitrates alone produce too active a melt, while carbonates alone do not furnish the desired oxidizing agents. Melts high in alkalies and made from batches containing alkali carbonates but no nitrates are difficult to fine properly. The chief function of alkalies in optical glass is to produce melts which are easily workable; they influence the viscosity of the melt; the viscosity of a potassium flint glass melt changes slowly with the temperature; that of a sodium flint glass changes fairly abruptly at a temperature somewhat above the softening

[1] See J. D. Cauwood and W. E. S. Turner, *J. Soc. Glass Techn.*, 1, 187 (1917); C. N. Fenner and J. B. Ferguson, *J. Am. Ceram. Soc.*, 1, 468 (1918); C. N. Fenner, *J. Am. Ceram. Soc.*, 2, 106 (1919).

[2] See Doelter, Handbuch der Mineralchemie (Leipzig), 1, 861 (1912); also E. T. Allen and E. G. Zies, *J. Am. Ceram. Soc.*, 1, 787 (1918).

[3] *J. Am. Ceram. Soc.*, 1, 767–794 (1918).

point. Increase in the total alkali content of a glass commonly raises its refractive index slightly; thus in the medium flint glasses an increase in alkalies with corresponding decrease in silica, the percentage of lead oxide remaining the same, raises the refractive index. Both alumina and magnesia may exert a profound effect on the viscosity of the melt. In the computation of batches from chemical analyses the data of table 4 are useful.

TABLE 4.

Table of molecular weights and ratios between molecular weights for use in the computation of glass batches from chemical analyses

Molecular weights

Al_2O_3	102.2	CoO	75.0	Na_2O	62.0	TiO_2	70.1
As_2O_3	197.9	CaO	56.1	NiO	74.7	U_2O_3	524.4
BaO	153.4	FeO	71.8	PbO	223.2	V_2O_3	150.0
Bi_2O_3	464.0	Fe_2O_3	159.7	SeO_2	111.2	ZnO	81.4
B_2O_3	70.0	K_2O	94.2	SiO_2	60.3	CO_2	44.0
CdO	128.4	Li_2O	29.9	SrO	103.6	N_2O_5	108.0
CaO	56.1	MgO	40.3	Sb_2O_3	288.4	Cl_2O_5	150.9
Cr_2O_3	152.0	MnO	70.9	SnO_2	141.0	SO_3	80.0

		Ratio of oxide to salt I	Reciprocal of I II
B_2O_3 to	$2B(OH)_3$	0.564	1.77
	$Na_2B_4I_7IOH_2O$	.366	2.73
	$Na_2B_4I_7$	.713	1.40
BaO to	$BaCO_3$	.777	1.29
	$BaSO_4$	.657	1.52
CaO to	$CaCO_3$	.560	1.78
	CaF_2	.718	1.39
K_2O to	K_2CO_3	.682	1.47
	$K_2CO_32H_2O$	.541	1.85
	K_2SO_4	.541	1.85
	$2KNO_3$	.466	2.15
	$2KClO_3$	.384	2.61
MgO to	$MgCO_3$	0.478	2.09
MnO to	MnO_2	.816	1.23
Na_2O to	Na_2CO_3	.585	1.71
	Na_2SO_4	.437	2.29
	$2NaNO_3$	.365	2.74
	$Na_2B_4O_7IOH_2O$	.162	6.11
	$Na_2B_4O_7$	.307	3.26
PbO to	Pb_3O_4	.977	1.02
	PbO_2	.933	1.07

Practical Applications

As an illustration of the use of the foregoing diagrams the batches for several different types of optical glasses will now be deduced.

(*a*) Ascertain the batch for an optical glass of refractive index $n_D = 1.649$ and $\nu = 33.7$.

By definition $\nu = (n_D-1)/(n_F-n_C)$; accordingly the mean dispersion of this glass is $0.649/33.7 = 0.01925$. From figure 2 we find that a glass of these properties is a member of the flint series; we may therefore turn directly to figures 8 to 12 for the desired information; the batch may be read off directly from figure 12 or obtained less directly from figures 8 and 9. The refractive index curve of figure 9 shows that the percentage of lead oxide, PbO, contained in a glass of refractive index $n_D = 1.649$ is 52; from figure 8 in turn we find that the approximate composition of a flint glass containing 52 per cent PbO is: SiO_2 41, PbO 52, and the alkalies (K_2O, or Na_2O, or $mK_2O + nNa_2O$) 7. By means of the conversion factors listed in table 4 we now convert the K_2O into a mixture of K_2CO_3 and KNO_3 such that the total amount of K_2CO_3 is three times that of KNO_3. A simple algebraic computation shows that this will be the case if 0.814 or roughly four-fifths of the total amount of K_2O is assigned to K_2CO_3 and the rest to KNO_3; the corresponding factor for Na_2O is 0.827. The batch then without allowance for volatilization is: Sand 100 kilograms or pounds, litharge (PbO) 126.8, potassium carbonate (anhydrous K_2CO_3) 20.4, potassium nitrate, 6.8. To correct for volatilization the lead oxide should be increased a little; as a first approximation subject to test and slight modification after a trial melt, we may write: Sand 100, litharge 127 (or red lead, Pb_3O_4, 130), potassium carbonate 20.5, potassium nitrate 6.8, and arsenious oxide (As_2O_3) 0.6,

The batch may also be read off directly from figure 12: sand 100, litharge 127, K_2CO_3 20, KNO_3 7. In the batch diagram as given arsenious oxide is not included; it is, however, common practice among glass-makers to add from 0.2 to 1 kilogram As_2O_3 per 100 sand. Too much arsenious oxide, especially in the flint glasses, may cause the glass to turn milky on cooling; but a little is considered to aid in producing a colorless glass of high, brilliant luster.

In case the analysis of the raw materials shows the presence of an appreciable amount of water in any one of the substances, such

as potassium carbonate, proper correction for this should be made in computing the actual batch to be used.

It should be understood that these batch figures are of the correct order of magnitude only; that the nice adjustment of the batch depends on a number of factors which are best ascertained by actual trial; these factors include size and type of melting pot and of melting furnace, resistance of the pot to attack by the glass melt, furnace schedule and treatment of the glass batch and melt. A departure of one or even two units in the third decimal place in the refractive index, and of one or two tenths in the ν-value may be found on actual trial. A slight modification of the relative quantities of the batch substance suffices commonly to produce the desired results.

(*b*) State the batch compositions of a glass of refractive index $n_D = 1.517$ and $\nu = 64.3$; $n_F - n_C = 0.00804$.

The ν-value of this glass is so high that it is evidently a borosilicate crown. Reference to the analyses of table 3 indicates that the optical constants of glass No. 17 are closely similar to those desired. In general it may be stated that for a borosilicate glass of such high ν-value, the refringence is unusually high, whereas for a crown glass of this refractive index, the ν-value is too high. The presence of boron oxide in the glass raises its ν-value; but, if added in quantity, it lowers the refractive index; barium oxide, on the other hand, tends to raise both the refractive index and the ν-value. It is evident, therefore, that in order to attain the higher refractive index, together with high ν-value, barium oxide should be substituted for the lime of the crown glasses and boron oxide should be present in appreciable quantities in order to approach the type of glass desired. The ν-value of glass No. 17 is too low; in order to raise it slightly the relative amount of boron oxide should be increased somewhat. A batch computed on the basis of analysis of 17 and modified in the manner indicated is the following: sand 100, $B(OH)_3$ 31, K_2CO_3 31, Na_2CO_3 21, KNO_3 5.2, $BaCO_3$ 6, As_2O_3 0.3.

In case a slightly lower ν-value as 64.1 or 64.0 is desired, the amount of $B(OH)_3$ should be reduced to 30 or even 29. The interplay of boron oxide and barium oxide in optical glasses, as affecting their dispersion and refringence, is a most inportant factor for the glass-maker to realize.

(*c*) State batch composition of a borosilicate crown of refractive index $n_D = 1.511$, $\nu = 63.5$.

In this glass the refractive index is low and the ν-value high; there is no necessity therefore of substituting BaO for CaO. Analyses 9, 10, and 11 may serve as a basis from which to deduce a batch composition for this glass; thus an appropriate batch would be: sand 100, $B(OH)_3$ 12, Na_2CO_3 22.6, K_2CO_3 15, KNO_3 9, $CaCO_3$ 4.5, As_2O_3 0.4.

(*d*) Select two glasses which in combination will produce a telescope objective nearly free from secondary spectrum.

Secondary spectrum in a well constructed telescope objective consisting of two glasses in combination results from the dissimilarity of dispersion in the two glasses. It can be readily proved that, other conditions being the same, the amount of secondary spectrum, for any spectrum interval, present in a doublet depends directly on the partial dispersion ratios of the two glasses and inversely on the difference between the ν-values.

The dispersion relations referred to in the foregoing pages enable us to select glasses which meet these requirements. They may in fact be selected directly by inspection of figure 4. As an illustration let it be required to select a suitable glass which may be used in combination with the zinc crown glass No. 26 of table 3 of glass analyses. The optical constants of this glass are: $n_D = 1.5128$; $\nu = 57.3$; $n_F - n_C = 0.00894$; $n_D - n_{A'} = 0.00575$; $n_F - n_D = 0.00630$; $n_{G'} - n_F = 0.00508$. The ratio $(n_D - n_{A'})/n_{G'} - n_F = 1.132$. From figure 4 we find that glass No. 45, a dense barium crown, has approximately the same ratio between the two partial dispersions, namely, $(n_D - n_{A'})/(n_{G'} - n_F) = 1.127$. Its optical constants are: $n_D = 1.6098$; $\nu = 58.8$; $n_F - n_C = 0.01037$ $n_D - n_{A'} = 0.00665$; $n_F - n_D = 0.00730$; $n_{G'} - n_F = 0.00590$. The partial dispersion ratios for the two glasses are:

No.	$\frac{n_D - n_{A'}}{n_F - n_C}$	$\frac{n_F - n_D}{n_F - n_C}$	$\frac{n_{G'} - n_F}{n_F - n_C}$
26	0.641	0.704	0.569
45	.642	.704	.569

From the analyses of these two glasses it is not a difficult matter to write down appropriate batches. Thus the batch for the

zinc silicate crown, No. 26, is approximately sand 100, zinc oxide 17.0, sodium carbonate (Na_2CO_3) 34.0, and sodium nitrate ($NaNO_3$) 11.3. A suitable first trial batch for the glass No. 46 is sand 100, boric acid ($B(OH)_3$) 69.5, alumina (Al_2O_3) 25.7, barium carbonate ($BaCO_3$) 199.5, arsenious oxide 3.0. The function of the alumina in this batch is to lessen the tendency of the barium oxide to form crystallization nuclei of barium disilicate and also to improve the working qualities of the melt itself.

From diagram 4 we note that a third glass, namely, the barium crown, No. 27, has almost the same dispersion relations; its ratio $(n_D-n_{A'})/(n_{G'}-n_F)$ is 1.132. Its partial dispersion ratios are 0.640, 0.703, and 0.565 for the intervals D to A', F to D, and G' to F, compared with the mean dispersion for the interval F to C. From analysis 27 a first trial batch composition may be computed by the methods outlined and found to be: sand 100, boric acid $B(OH)_3$ 9.0, zinc oxide 8.4, barium carbonate 41.7, sodium carbonate 9.0, potassium carbonate 18.5, potassium nitrate 9.5, arsenious oxide 0.5. The addition of more barium carbonate to this batch would raise the refractive index. As the amount of BaO is raised, that of the alkalies is lowered in order partly to reduce the corrosive action of the melt on the pot.

These examples suffice to indicate that the problem of batch compositions of optical glasses is one of interpolation, together with a certain amount of experience which enables the glass-maker to determine what the behavior of the melt will be and other questions of a similar kind. In all cases it is advisable to prepare small charge melts, 5 to 50 kilograms in weight, to stir these properly, and to ascertain on the finished glass its optical constants. Good quality glass can not be attained by this procedure and the conditions are distinctly different from those in the melt of a large charge of 500 to 1000 kilograms; but the order of magnitude of the optical constants obtained is correct. It is also advisable to hold the small charge melt for a relatively long period of time at temperatures somewhat below the final stirring temperatures in order to ascertain the tendency of the melt to crystallize or to become milky and opalescent; the batch can then be modified accordingly.

It may be of interest to note that this part of the general prob-

lem of optical glass manufacture proved, during the war, to be one of the least of our troubles and indicated the futility of secrecy in this particular phase of optical glass manufacture. As a research problem, the general task of optical glass manufacture in war time differs from ordinary research problems because the properties of the final product are definitely known and the task is to reproduce glasses of known characteristics rather than to develop new types of glasses.

Summary

The manufacture of optical glass as a war-time problem required the solution of many different problems in order to establish it on a definite basis of routine quantity-production. One of these problems was the development of suitable batches for the several types of optical glasses needed in military optical instruments. This necessitated a detailed study of the relations between chemical compositions and optical constants of glasses and of the factors, such as volatilization, pot solution, state of annealing, which tend to change the relations during the manufacture of the glass. The amount of accurate information available at the time, especially of a chemical nature, was meager, but exceedingly valuable to us. The problem was accordingly attacked by graphical methods and solved sufficiently to enable us to write down the approximately correct batches for the types of glass which were urgently required. A few experimental melts enabled us then to correct for errors arising from selective volatilization and the like, and thus to set up satisfactory batch compositions.

In this paper the several factors involved are presented chiefly in graphical form; the dispersion relations alone are first considered, after which the chemical characteristics and the relations between chemical composition and optical constants are treated in summarized diagrams to indicate the methods which we adopted and which enabled us to solve the problems in a practical way in a short time. No consideration is given to the more fundamental problem of computing the optical constants of a glass of given

chemical composition.[1] The information at hand was not adequate for this purpose and our war-time interest was not concerned with this problem which still awaits satisfactory solution.

GEOPHYSICAL LABORATORY
CARNEGIE INSTITUTION OF WASHINGTON
WASHINGTON, D. C.

NOTICE.—*Further discussion of this subject is solicited. All communications should be sent to the Editor*

[1] The first five papers of a series of articles on "The development of various types of glasses" have recently been published by C. J. Peddle in *Jour. Soc. Glass Technology*, **4**, 3–107 (1920); see also "The optical properties of some lime-soda glasses," by J. R. Clark and W. E. S. Turner, *Jour. Soc. Glass Technology*, **4**, 111–115 (1920).

THE CONSTRUCTION OF A NOVEL TESTING FURNACE[1]

By S. F. Walton

In constructing a furnace for testing ceramic products, it was decided to avail ourselves of the down-draft principle so as to protect the head of the testing machine from heat. It is, primarily, as the cut shows, constructed of fire-brick. The base contains the cross flue, the center well hole and the main flue to the chimney. Above this base a circular wall was formed of segmental circular brick $4 \times 4 \times 1^1/_2$ inches with $10^1/_2$-inch radius. These brick were made in the laboratory of a special highly refractory silicon carbide mix. Back of this wall is an inch and half of "Sil-o-Cel" tamped in place, and a four and a half inch wall of circle fire clay brick. On account of limited space the chimney or stack had to be built into the wall of the furnace. The floor between the flue openings was built of silicon carbide refractory, to resist impact, and the circular muffle, which is in two halves, is of similar material. The knife edges, on which the test pieces for cross breaking are set, are shown inside of this muffle. They are placed 6 inches center to center. The ports for the gas burners were set tangential to the circular wall and were formed of galvanized iron. Fire clay was packed around these except where it passed through the inner wall where silicon carbide cement was used. As the metal burnt away it left the refractory material baked in shape, and no cracks have developed.

The position of the furnace made it necessary to build a long flue from the top of the chimney proper to connect with the flue of a muffle furnace and out to the main stack. This flue is of some interest as it is constructed by placing a five inch galvanized iron pipe inside of a seven-inch and filling the annular space with Johns-Manville No. 26 refractory cement. The inside pipe has burnt out in places but the cement has set firm. The result is a flue which withstands the high temperature of our exit gases and yet is of simple and inexpensive construction.

[1] Received Feb. 27, 1920.

To use this furnace for cross-breaking tests (it is obvious that it is not limited to that use alone) a lever arrangement was set up as is shown in the second cut. A six-inch I-beam *A* is supported on knife edges in the stand *B*. The lever ratio is one to two. The knife edge of the refractory pressure block *E* is centered on the test piece, the latter resting on the knife edges bedded into the floor of the furnace as previously described. These

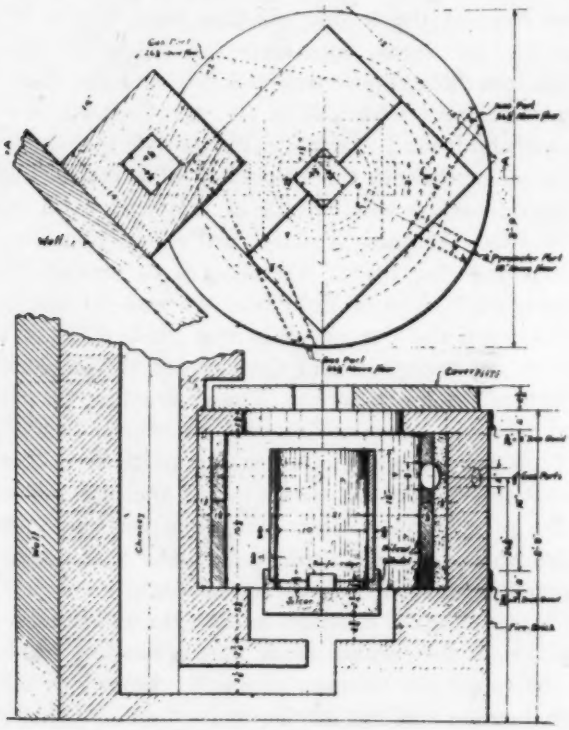


FIG. 1.—Test furnace.

knife edges, and the pressure block, were made of a special high grade silicon carbide refractory. The pressure block fits into a recess in the head *I*, which is suspended on steel knife edges. A similar head is at the other end of the *I* beam. A chain jack *C*, which has a handle fastened to the sprocket wheel, is set on the platform scale *D* with the plate in the recess of the head.

A Mariotte's bottle *G* and a bucket *H* hung from the balance arm of the platform scale complete the equipment,

The operation is as follows: The test piece, preferably 2 × 2 × 8 inches, is set on the knife edges and the pressure block set on top with its knife edge centered. The gas is lighted and the temperature brought up to 1000° C in four hours. A time-temperature curve is plotted by means of a noble metal thermocouple set within a half inch of the test piece, which records on a Leeds and Northrup curve drawing potentiometer. After holding for twenty minutes at the required temperature to allow even distribution of heat the load is gradually applied.

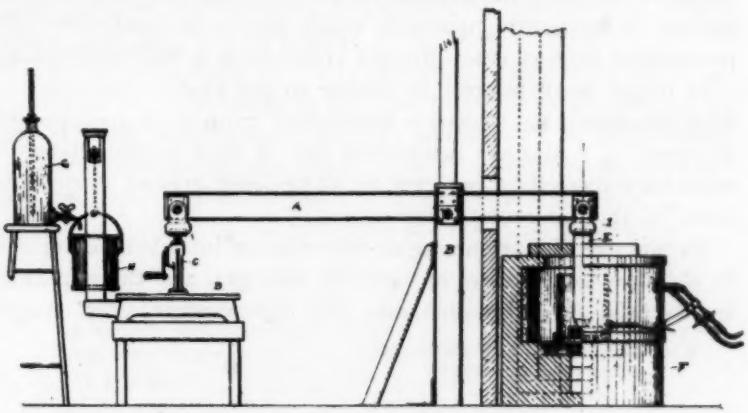


FIG. 2.—Test furnace layout.

The system has meanwhile been balanced so that the scale balance arm is horizontal. Water running into the bucket *H* continuously disturbs this balance which is continually renewed by screwing up the jack. The water is allowed to run in at a uniform rate sufficient to increase the load by 80 pounds per minute. The load is increased until rupture takes place. The ratio of the levers on the platform scale is one to one hundred and the ratio of load in the bucket to the load applied on the test piece is then one to two hundred.

At the moment of rupture the supply of water is shut off and the amount in the bucket weighed. Two hundred times this

plus the weight of the pressure block gives the load applied. This amount is substituted for P in the formula $\frac{3}{2}\frac{P l}{b d^2}$ = modulus of rupture.

The data required in each case is the cross section, width, and depth of the piece, appearance of fracture and the total time in minutes of applying the load. The latter is simply a check on the rate of increase of load. By use of a Mariotte's bottle the flow of water was practically constant. This method of applying the load is much more satisfactory than the use of shot.

The whole apparatus is much simpler than any I have seen discussed in the Transactions or the Journal, and for the comparison of refractory materials which are to be used where the modulus of rupture is an effective criterion, it is very satisfactory.

It might be of interest in closing to say that a refractory we have developed has shown a modulus of rupture of 5000 pounds at 1000° C. Another interesting fact is that certain classes of refractory showed 25 per cent to 35 per cent greater strength at 1000° C than at room temperatures.

By the use of a premixing device recently installed we are able to obtain a temperature of 1450° C with gas, and the apparatus can be used at, and withstands, this temperature satisfactorily.

KALMUS, COMSTOCK & WESCOTT, INC.
110 BROOKLINE AVENUE
BOSTON, MASS.

NOTICE.—*Further discussion of this subject is solicited. All communications should be sent to the Editor*

THE RATE OF VITRIFICATION OF PORCELAIN MOLDED UNDER DIFFERENT CONDITIONS,[1,2]

By R. F. Sherwood

It is a well known fact to ceramists that the initial structure of a clay body governs, to a certain extent, the rate of contraction and vitrification. Thus it might be expected that a dry pressed body will vitrify at a different rate than one which has been molded by hand or cast. Although some numerical data are available, particularly with reference to the dry or semi-dry pressing process, there is still lack of information on this important subject.

In the present work it was endeavored to show the difference in the rate of vitrification of one and the same body, molded by hand pressing in the plastic state, by casting and by dry pressing at different pressures, and finally fired simultneously in the same kiln, and hence subject to identical heat treatment.

The composition of the porcelain body was as follows:

Feldspar	22%
Flint	31
Tennessee ball clay No. 5	12
English china clay	25
Florida kaolin	10

This mixture was made up into briquettes about 2 × 1 × 1 inch, by three processes, pressing in the plastic state by hand, using a plaster mold, casting in a similar mold, with the use of 0.2 per cent of sodium silicate and sodium carbonate, and pressing in a steel mold at the pressures of 2,000, 4,000 and 6,000 pounds per square inch. The pressure was obtained on an Olsen testing machine set to exert the required load.

The water content of the dry pressed specimens was between 6–7 per cent, except with E, where it was only 1.12 per cent.

The weights of the pieces in the dried state were 1.67 grams per cubic centimeter for the body molded in the plastic state,

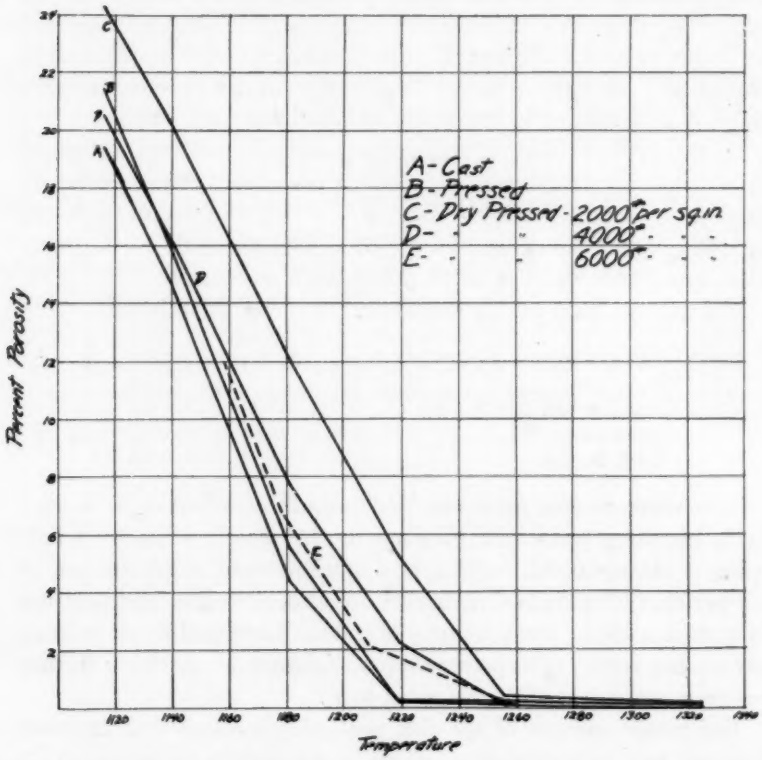
[1] Received Feb. 27, 1920.

[2] By permission of the Director, Bureau of Standards.

1.76 grams for the cast, 1.71 grams pressed at 2,000, 1.73 grams pressed at 4,000, and 1.78 grams pressed at 6,000 pounds per square inch.

The densest mass is thus produced by dry-pressing at 6,000 pounds per square inch, followed by the casting process, dry pressing at the lower pressures, and finally by molding in the plastic state.

The briquettes, after thorough drying, were fired in a large test kiln with a temperature increase of 20° C per hour, above



800° C, under conditions accurately controlled by pyrometer measurements and the use of cones.

At regular intervals three of each kind of trial pieces were withdrawn from the kiln in the customary manner. The speci-

mens pressed at 6,000 pounds per square inch were fired in a different burn and hence were subjected to slightly different conditions.

The porosity of the briquettes was determined in the usual manner. The results correlating these values with the temperatures are shown graphically on the accompanying diagram.

The curves show that down to a certain point, say a porosity of 2 per cent, the mean rate of vitrification is greatest for the body molded in the plastic state, followed in order by the cast and dry-pressed specimens, the lowest rate being shown as is to be expected by the one preessd at the lowest pressure. By mean rate of vitrification is meant the drop in porosity corresponding to a definite increase in temperature, or the differential of the curve, $\frac{dy}{dx}$, expressed by its tangent, it being assumed that the relation is a linear one. These values then would be as follows:

A. Cast body	0.200
B. Plastic molded	.214
C. Dry pressed, 2000 lbs	.174
D. Dry pressed, 4000 lbs	.171
E. Dry pressed, 6000 lbs	.174

The point corresponding to two per cent porosity is reached by the different specimens at the following temperatures:

A. Cast body	1202° C
B. Plastic pressed	1206
C. Dry pressed, 2000 lbs	1243
D. Dry pressed, 4000 lbs	1223
E. Dry pressed, 6000 lbs	1210

Minimum porosity, close to vitrification, is reached with the several methods of molding, as follows:

A. Cast	1219° C.
B. Plastic pressed	1219
C. Dry pressed, 2000 lbs	1256
D. Dry pressed, 4000 lbs	1255
E. Dry pressed, 6000 lbs	1255

From the data obtained it appears, first, that the initial structure of the body dry-pressed at 6,000 pounds per square inch is

most dense and that of the plastic material least so. At 1120° C the initial porosity is lowest in the case of the cast body and greatest for dry pressing at the least pressure. The porosity of the material pressed in the plastic state occupies an intermediate position.

Second, the rate of vitrification is most rapid for the plastically molded body, followed by the cast material. The rate of condensation for the dry-pressed body is markedly slower though it seems that greater pressure accelerates the vitrification process. There appears to be a distinct difference in heat effect when comparing the wet-molded with the dry-pressed material and probably also greater heat absorption. There appears to be little difference between the heat behavior of the cast as against the plastic pressed body though some distinction is discernible and it is reasonable to assume that more heat units will be absorbed in bringing about equivalent changes of unit mass of the cast than with the plastic pressed material.

Third, for a given degree of porosity not too far removed from complete vitrification the cast body reaches such a point at the lowest and the dry-pressed material at higher temperatures, according to the pressure applied. The temperature difference between the extremes is about 40° C, roughly equivalent to two cones.

Fourth, minimum porosity is reached practically simultaneously by the cast and plastic pressed body and also simultaneously by the body molded at the pressures of 4,000 and 6,000 pounds per square inch. The one pressed at 2,000 pounds shows a slight lag.

Fifth, complete vitrification indicated by zero apparent porosity is not reached at the maximum temperature employed, 1325° C, by the body molded in the plastic state nor by the one subjected to dry pressing at 2,000 pounds. It is attained by the material molded by the other processes. It would seem, therefore, that the degree of compactness governs also the temperature at which complete vitrification takes place or the time during which a given temperature must be maintained.

Bureau of Standards
Washington, D. C.

Discussion

MR. GEORGE SIMCOE.—How was the power applied in the case of the 6,000 pound pressure dust pressed sample, continuously or intermittently, giving the clay a chance to free itself of air? Our experience in the manufacture of dust-pressed ware requires us to air the piece, as we term it; that is, apply a slight pressure at first then relieve the same. In some instances we use the foot treadle to bring the piece above the top of the die so that the sides may have a chance to permit the air to go out. Otherwise the piece is liable to have laminations which occur at right angles to the direction of the power applied.

AUTHOR'S REPLY.—The pressure on the die was applied very slowly, by an Olsen testing machine. Hence it was unnecessary to air the piece to prevent laminations, because of the pressure being applied much more slowly than in the manufacture of dust-pressed ware. However, the trials that contained but two per cent of water when they were pressed were found to crack very slightly when fired to cone 14. In the case of the other trials no laminations were found.

NOTICE.—*Further discussion of this subject is solicited. All communications should be sent to the Editor.*

OIL FIRING OF KILNS*

By F. A. Whitaker

During the latter part of 1919, we conducted a series of tests in the burning of chemical stoneware, using fuel oil in place of gas coal.

It was our intention to simplify the present complicated burning process and, if possible, lessen the cost of this operation and at the same time make ourselves independent of the coal supply which is at present very irregular both as to quantity and quality.

To this end, we equipped one of our small kilns with a low-pressure fuel-oil equipment furnished by a firm prominent in this line of work. The kiln used in these tests was rectangular in shape, measuring about 12 × 12 × 8 feet high inside. It was of the open fire, down-draught type, furnished with four fire holes, two on each side.

The oil used was Western, light in contrast to the heavy Mexican oil, which is used for other purposes. For these tests, we arranged for a temporary gravity feed and the necessary air was carried through a 4-inch galvanized pipe line from the blower at a pressure of about four pounds.

On each of the four fire holes of the kiln, we placed two $1^1/_4$-inch burners in the combustion chamber proper, and in the ash pit $^3/_4$-inch burners, the grate bars, of course, having been removed. The reason for this was that we wanted to start with a very small flame, and we expected trouble in keeping the larger burners lit if turned very low.

No change was made in the design of the fire boxes except that the grate and cross bars supporting these were removed and the front of the fire hole was bricked up, leaving just a small slit for the flame from the burners to enter. The flames impinged upon a special carborundum block which distributed the fire into the combustion chamber in a fan shape.

At the commencement of the burn, two of the small burners were started in diagonally opposite corners and about six hours

* Received February 27, 1920.

later, the other two small burners were started. These burners were gradually opened until after 25 hours' firing, the interior of the kiln commenced to get red. When the small burners had developed their maximum heat, they were shut off and the larger burners put into operation and finally we had all eight burners going at the same time.

On this first test, we found it impossible to mature the ware at the bottom of the kiln, although the upper part was nicely finished, and so on the next test we used 2-inch burners for finishing instead of $1\frac{1}{2}$-inch and improved the results considerably. Our main trouble, however, remained, *i. e.*, that there was a considerable drop in temperature from the fire box to the bottom of the kiln, and it would have been impossible to mature the latter without overfiring the top and probably burning out the fire box lining. This convinced us that the type of burner we were using was not satisfactory for the purpose and subsequent conversations with other parties using fuel oil, showed us that this was undoubtedly the case.

Unfortunately we were not able to make more than three trial burns, owing to the difficulty in procuring the necessary oil, but the experience we had, convinced us that although the actual cost in fuel consumed was considerably higher than when using gas coal, the ease in control and consequent possibility, up to a certain extent, of standardizing the burning process convinced the writer that this method of firing would have big advantages in the firing of such complicated material as chemical stoneware.

In conclusion, I would state that we had no difficulty in closely controlling the advance in temperature or composition of the fire gases, and our only trouble lay in attempting to get an even distribution of the heat and a long flame, which could undoubtedly be overcome by finding the right type of burner.

We had no difficulty in salt glazing the ware. For this purpose, we constructed a special injector which blew the salt into the combustion chamber in a fine stream with the help of compressed air.

GENERAL CERAMICS COMPANY
KEASBEY, N. J.

DISCUSSION

MR. D. W. ROSS: The gentleman said he did not want the firing to be at the mercy of the foreman in charge. On the Pacific Coast several concerns were using oil in burning hollow ware. It gave the fireman a tremendous weapon, because he could go to pretty near any temperature he wanted, and it was easy for him to melt down the top five or six course of hollow ware and then wake up an hour or two later and find out what he had done. The oil could supply such a tremendous heat in such a short time that, although it was nice to work with, it was very dangerous with workmen who were not very reliable.

MR. A. P. GORTON: The whole matter was threshed out quite a number of years ago in 1892, by Thomas Gray, a New England potter, and the various devices he had to resort to are well described in our Transactions, Volume XV, page 661. I think every one attempting to use oil for the first time has about the same experience, the concentration of heat in the firing box and the difficulty in communicating that heat to the interior of the kiln. I might say that we have used fuel oil during the winter in firing tank block kilns, and we believe with considerable success. In firing time, we have effected a saving of at least two days over firing with coal, and this saving has been accomplished mostly by the fact that with oil we can effect a regular progression in the time temperature curve. I would like to ask Mr. Whitaker in this connection what was used to spray the oil, that is, whether steam or air, and under what pressure, since that has a lot to do with the results obtained? We started to use high pressure air, at about 75 pounds, and had this trouble of the fire box getting enormously hot. The trouble was overcome to a great extent by the substitution of steam at 80 pounds, and we found that the fire box was much cooler and the combustion projected more into the kiln. We have also tried this same method on our continuous tunnel kiln at Carbon, Mo., in the burning of high grade fire brick, and have had just as much success there. As to the expense, it is very nearly as cheap as burning coal in the solid condition.

PROF. C. F. BINNS: If the members will turn to volume 1 of the Transactions of the American Ceramic Society, they will

find this subject discussed by Stanley G. Burt. He raised this very point. He stated that in order to get cone 5 in the kiln he had to reach nearly cone 25 at the burner, and he came to the Society at that first meeting to find how to get over the trouble.

MR. D. H. APPLEGATE, JR.: The difficulty which most people get into in substituting oil for coal fuel is that they attempt to put the oil flame into the coal fire box without other changes than to cover the grates with fire brick and to brick up part of the door space. This is a great mistake.

The coal fire box is necessarily deep to allow for the fuel bed and combustion space above it. With an oil fire this provides a large combustion chamber close to the burner and causes an intense heat to be developed at that point. This burns out the fire box and produces a condition of constantly diminishing temperature as the gases diffuse throughout the kiln and advance toward the exit.

A properly designed oil furnace should be approximately funnel shaped with the small end next to the burner and with the bottom sweeping on an easy curve into the bag. The cross-sectional area of the furnace should be slightly less than that of the bag at the junction of the two. This will provide for the expansion of the flame as it proceeds, but will confine it without undue restriction at any point and will cause it to maintain its velocity and carry well into the kiln before combustion is entirely completed. It is possible to make the flame extend to the bottom of the kiln and still have good combustion conditions.

To adapt a coal furnace to oil burning, the bed should be built up with fire brick and covered with fire sand so that it will slope slightly upward from the mouth toward the bag wall and will join the latter in an easy curve which should become tangent to it. The distance from the bed to the edge of the fire arch at its highest point should be 1 to $1^1/_2$ times the width of the bag, depending on the spread of the flame. The latter should be so directed as to be close to the sand bed of the furnace and to avoid direct contact with the arch.

My experience agrees with that of Doctor Gorton in that steam at not less than 60 pounds pressure is a better atomizing agent than compressed air for producing an even temperature

throughout the kiln, but steam to be successfully used for this purpose must be superheated, and the superheating furnace should be close to the burners. The use of too much or too wet steam will, however, cause a waste of oil as it forms a large volume of inert gas which must be heated and passed through the kiln. To overcome this tendency I tried forcing air under slight pressure from a blower through a longitudinal slot in the bed of the furnace directly under the path of the flame. That relieved the burner from the necessity of forcing the full requirement of air into the furnace and so saved much steam. It effected a saving of about 15 per cent in the oil consumed and still gave the advantage of the steam in producing a long easy flame. A considerable part of the air is carried under the flame and does not completely combine with it until well into the kiln.

There was much less wear on the fire boxes in this method of burning than when coal was used and there was little difficulty in getting an even heat throughout the kiln. I have burned kilns of brick in this way with a difference of less than two cones between the top of the setting next to the crown and the course next to the floor.

NOTICE.—*Further discussion of this subject is solicited. All communications should be sent to the Editor.*

CERAMIC ABSTRACTS[1]

General

The electro-osmotic process in ceramics. F. SINGER. *Berichte der Technisch-wissenschaftlichen Abteilung des Verbandes keramischer Gewerke in Deutschland,* **5,** 16–23 (1919).—A thorough refining is not obtained by the older methods of refining kaolins since the specific gravities of many of the impurities is almost the same as that of kaolin and hence the finer impurities are not removed by gravity methods. In the electro osmotic process a predetermined weight of electrolyte is added to the slip and the impurities such as quartz, spar, iron pyrites and mica settle to some extent while the clay with the finer impurities remain in suspension. The electric current is then turned on and the electro negative clay is attracted to the anode while the positive impurities are repelled to the cathode. The water content of purified kaolin is 30–35% while that of plastic clays is 15–25%. Tostmann found that where kaolin is washed in the ordinary method he was continually troubled with spots and flaws in cast ware, whereas ware cast with electro-osmosed clay was perfect. This is probably due to the freedom from fine mica in the osmosed clay. H. G. SCHURECHT.

The properties of some stoneware clays. H. G. SCHURECHT. *Tech. Paper,* **233,** U. S. Bureau of Mine, 1920, 42 pp., 1 pl. and 23 figs. See *Jour. Amer. Ceram. Soc.,* **1,** 267–286 (1918). H. G. SCHURECHT.

A new process of centrifugal filtration. W. G. GEE. *J. Soc. Chem. Ind.,* **39,** 301–2T (1920).—This article describes the construction of a centrifugal filter of the solid drum type having as a new feature a removable lining. The solid material is deposited in a layer on this lining and then the lining is elevated from the drum and the solids are quickly removed. The removal of the recovered solids is said to require much less time than the cleaning of a filter press and the cleaning of filter cloths. A. J. LAMBERT.

The physical properties of stoneware glazes. R. RIEKE. *Berichte der Technisch-wissenschaftlichen Abteilung des Verbandes keramische Gewerke,* **5,** 8–15 (1919).—In general it might be said that crazing of glazes is due to a difference in the coef. of expans. of the glaze and body. Although a high elasticity and tensile strength may prevent crazing where the expansion of the body and glaze are different, such glazes are not very durable as they often craze after a long time. For hard burned porcelains and porcelain glazes the expansion increases uniformily with an increase in temp. The coefs.

[1] The abbreviation (*C. A.*) at the end of an abstract indicates that the abstract was secured from the Editor of Chemical Abstracts by coöperative agreement.

of expans. of Berlin tech. porcelain at 700° C. is 35.10^{-7} while porcelain glazes vary from 27.10^{-7} to 42.10^{-7}. It is possible therefore to pick glazes which have the same coef. of expans. as the porcelain. With stoneware it is impossible to get a glaze which expands and contracts the same as the body since stoneware bodies always contain considerable free silica. Cristobalite has a sudden change in volume at 200° C. Since even low melting glazes are no longer soft at 200° C., the stoneware in contracting suddenly at 200° C. in cooling causes cracks in the body or glaze. Furthermore with glazes which harden above 500° C., strains are produced due to the conversion of *a* to *b* quartz at 575° C. The coef. of washed kaolin is about 40.10^{-7} to 80.10^{-7}. A stoneware containing 25 per cent flint and fired at cone 7 had a coef. of expans. of 130.10^{-7} between 15° C. and 200° C., 70.10^{-7} between 200° C. and 500° C., 140.10^{-7} between 500° C. and 600° C. and 50.10^{-7} between 600° C. and 1000° C. The coef. of expans. of stoneware glazes varies between 57.10^{-7} and 96.10^{-7}. It is therefore impossible to fit a glaze to a stoneware body with such varying expansions. The mod. of elast. of a glaze varies between 5700 to 6800 kg./sq. mm. which is a very small range. It may be said therefore that the coef. expans. of glazes may be varied between comparatively wide limits by means of their chemical composition but the mod. of elast. can be varied but slightly by this method. The tens. strength of the majority of stoneware glazes probably lie between 5 to 8 kg./sq. mm. although some lie as low as 3.5 kg./sq. mm. Of the above properties the coef. of expans. is the most important. The tens. strength is more important than the mod. of elast. For ex. if two glazes have a mod. of elast. of 5000 and 7000 kgs./sq. mm. respectively and a tens. strength of 5 kg./sq. mm. a rod 10 cm. long would be expanded 0.10 mm. and 0.07 mm. respectively with a tension of 5 kg./sq. mm. If the tens. strength is 8 kgs./sq. mm. and the maximum tension applied the expansion would be 0.17 mm. and 0.11 mm. respectively for the glazes with different mod. of elast.

H. G. SCHURECHT.

Surface combustion. A. E. BLAKE. *Proc. Eng. Soc. Western Pa.*, **36**, 145–204 (1920).—This term was originally used for the catalytic action of metals and later non-metallic refractories upon homogeneous, explosive gas mixts. B. applies it to a flameless, complete, and exceedingly rapid oxidation, attained in a special design of furnace. This involves the use of a perfect mixt. whose advantages are (1) the release of total available energy; (2) a minimum reaction vol., giving max. heat concn. and max. temp.; (3) an instantaneous combustion leaving max. time for heat transfer before products of combustion reach flue; (4) the smallness of reaction zone, avoiding danger of injury to work and permitting smaller furnace design and (5) the superior radiation of incandescent material over more or less sooty flame. Among the disadvantages of an imperfect mixt. are the loss of energy absorbed by inactive air, slowing down of reaction due to diln., and detrimental effect of oxidizing atms. within the furnace. The original underfired-refractory type of furnace caused great trouble in keeping the ports open, but now an inclined

tube projects the perfect mixt. into a pocketed bed of refractory, which becomes incandescent. A higher temp. is permissible here than the furnace lining could stand. In another type the mixt. is delivered from a nozzle to the base of a refractory-lined tunnel, which acquires incandescence and effects complete combustion rapidly. Of most importance is the production of a perfect or const. mixt., which is done by low- or high-pressure automatic devices on the Venturi principle. Once set, it will deliver const. proportions throughout the range of the app. Accompanying illustrations present examples of furnace engineering in the industrial applications of surface combustion; very remarkable results in steam generation have been attained in England. A bibliography is appended. In discussion, considerable attention was given to refractories, the practicability of remodelling furnaces for surface combustion, the failure of the present 2-valve control, and the fact that no claim can be made of originality in the use of a perfect mixt.

[*C. A.*]

PATENTS

Kiln. CHARLES E. CARPENTER. U. S. 1,349,185, Aug. 10, 1920. A kiln bottom comprising a pair of crossed flues communicating with each other at their point of intersection, one of the flues being open at the top to communication with the interior of the kiln and one end of the other flue forming an outlet to a stack. An annular flue intersects and communicates with the crossed flues and is open at the top to communication with the interior of the kiln.

Drier-tray. CARL EDWARD JOHNSON. U. S. 1,349,458, Aug. 10, 1920. This describes a tray made from angle strips in such a manner that the angle irons form U-shaped channels for the passage of hot air.

Non-metallic resistance element and process of making same. ALEXANDER L. FEILD. U. S. 1,349,053, Aug. 10, 1920. An electric resistance element containing a compound of a metal of the titanium-zirconium group, and a refractory oxide, the element having a substantially zero temperature resistance coefficient.

Drier. JOHN O. TENSFELDT. U. S. 1,349,590, Aug. 17, 1920. A drier comprising a chamber having mounted therein: a drying chamber, a distributer of heated air, and a chamber beneath said drying chamber adapted to receive moistened air from the same. The drier has means connected therewith for circulating the air through the chamber, extracting the moisture from the air, and heating the air. The distributer comprises a longitudinal channel and a plurality of side channels arranged at intervals and provided with perforations in the bottom whereby the heated air is delivered at intervals and in a downward direction.

Pot-furnace. ELMER L. KNOEDLER. U. S. 1,349,159, Aug. 10, 1920. A pot furnace, comprising a tiltable pot, means whereby heat may be applied

thereto, and stirring means mounted on the pot to rotate therein about an axis which is at an angle to the tilting axis of the pot. C. M. SAEGER, JR.

Artificial stone. H. GRÖNROOS. Brit. 138,799, June 4, 1919. Nearly equal parts of porcelain or faience refuse, powdered pipeclay, and crushed glass are mixed together with a little H_2O and poured into a mold the bottom of which is covered with crushed glass. Pressure of about 2850 lb. per sq. in. is applied and the material is then exposed to a temp. of 900–1200° to produce an artificial stone or marble-like slab having a glazed surface. Variegated effects are produced by using glass of various colors. Cf. *C. A.* **14**, 2249. [*C. A.*]

Drying china-clay. J. ADAIR. Brit. 142,161, Dec. 16, 1918. An app. comprizes a combination of mechanical loading-app., drying-floors with heating means, and means connected with the floors for unloading the dried clay from the floors. The settling-tank is formed with inclined bottom parts leading to an inclined central channel which is fitted with a worm or chain-scraper to discharge the clay into a receiver, from which it is delivered by an elevator to a travelling tray or hopper above the drying floors. The hopper is mounted upon wheels and has bottom parts which open downward to allow the clay to fall on to the floors. The drying floors or trays may be stationary or travelling on wheels, and their bottom parts flat or corrugated. A suitable construction is specified. [*C. A.*]

Refractories

Transverse strength of fire clay tile. Bur. of Standards, *Tech. News Bull*, **40** (1920). Anonymous.—A number of tests have just been completed on fire clay tile subjected to a temperature of 1350° C. in order to determine the modulus of rupture and the deformation. The surprising fact was brought out that these tiles, in spite of their weight and bulk ,can not support any appreciable load beyond their own weight, and in the case of long spans it was found that the tiles broke without any imposed load. It is quite possible that for load-carrying refractories of this type, entirely different compositions and combinations of clay and grog must be resorted to. A. J. LAMBERT.

Carborundum coating for fire-brick. P. M. GREMPE. *Brit. Clayworker*, **29**, 113 (1920).—G. in the Jour. für Gasbeleuchtung discusses the use of carborundum as a coating for refractory brick. It has been found that, with a sufficient coating, the fire-brick need not be so refractory. Seventy-five per cent carborundum and 25 per cent water glass make an excellent coating. If fire brick are basic 85 per cent carborundum and 15 per cent clay may be used. The brick should be thoroughly dry before the coating is applied a layer of 0.02 in. is thick enough for even the highest temps. The coating is allowed to dry 24 hrs. and then is heated up very slowly. The coating becomes burned into the brick and there is left a firmly adherent glassy coating of carborundum which resists mechanical injury and shelters the fire brick

from the chem. action of the flames. The coating is remarkably insensitive to sudden temp. changes. The coating can be applied to every part of a producer, including firebars. A half years working with daily heating and cooling did not injure the lining in the least. Gas retorts have their life increased by coating them inside and out. Cracks in retorts can be promptly repaired by a mixture of 50 carborundum and 50 clay, worked up with water, even when the retort is hot. H. G. SCHURECHT.

Refractories for the glass industry. Bur. of Standards, *Tech, News Bull.* **40** (1920). Anonymous.—The Bureau has commenced an investigation having for its object the development of improved refractories out of which to construct pots, and so forth, for the glass industry with particular reference to their resistance to corrosion. The principle adopted has been to systematically study such bodies composed of siliceous bond clays mixed with aluminous grog and of aluminous bond with siliceous grog. A large number of crucibles have already been made from these mixtures. These will be subjected to the action of a corrosive barium glass. Upon breaking the crucibles, the depth of penetration and degree of attack of the glass upon the material of the crucible will be determined. In addition, the transverse strength of the mixture, both in the dried and in the fired state, as well as the shrinkage will be measured. A. J. LAMBERT.

Investigation of combination of aluminous and siliceous bond clays used in making of crucibles. Bur. of Standards, *Tech. News Bull.* **40** (1920). Anonymous.—The search begun during the war for American clays to replace German clays in making crucibles and glass pots is now being extended and will soon be completed. Small pots have been made from various combinations of aluminous and siliceous bond clays and will be subjected to the corrosive action of various kinds of glasses. It has been found that when used with 50 per cent grog, Arkansas kaolin has even a lower shrinkage and higher porosity than the famous German Gross Almerode clay. A. J. LAMBERT.

PATENTS

Refractory substances. G. I. DIMITRI. Brit. 142,512, May 1, 1920. Natural Mg silicates such as talc, steatite, Briancon chalk, are mixed in a powdered state with a flux consisting of natural or artificial multiple silicates such as feldspars, mica pyroxene or the like or with rocks containing them, as granite, gneiss, porphyry, pegmatite. The mixt. is prepd. moist or in powder form, dried, shaped, and burned at about 1450° to produce refractory and elec. insulating articles. [*C. A.*]

Lining retorts and furnaces. S. A. MCMINN. Brit. 137,419, Feb. 28, 1919. A mixt. contg. 30 per cent or more of powdered glass, together with fire-clay, such as Stourbridge or china clay, or a clay contg. over 90 per cent SiO_2 is used as a glazing-cement for lining retorts or furnaces. A mixt. of china clay with SiO_2 clay and ground glass in equal proportions may be employed. Cf. *C. A.* **14**, 2247. [*C. A.*]

Glass

The glass melting furnace. ANON. *Glasindustrie*, **31**, 97–8, 105–6(1920).—*Pot Furnaces.* The Siemens furnace, with regenerators beneath the furnace is typical of the regenerative type. The Nehse and Siebert furnaces are typical of the recuperative type. The Siemens furnace now costs 12–15000; the Siebert 10–12000 and the Nehse, 9–10000 marks. Checker brick are usually 250 × 120 × 65 mm. or 250 × 80 × 80 mm. and space between bricks is 60–80 mm. Bricks should not be over 80 mm. thick. Ironing of the furnace is one of the most important points in construction. The advantages claimed for tanks are (1) greater production, (2) economy of fuel, (3) freedom from delays with pots, (4) use of lower alkali and therefore cheaper glass mixtures, (5) less skill required in operation. The regenerative type tanks are the Siemens, Gobbe, Henning and Wrede and Klattenhoff. The recuperative type tanks are the Nehse, Dralle and the Nehse-Dralle. Approximate costs are given for various constructions. C. H. KERR.

The manufacture of especially pure sodium sulfate for use in the production of highest grade crystal glass. K. KILLER. *Sprechsaal*, **53**, 93–4(1920).—Ordinary salt cake used in the glass industry contains about 1 per cent SO_3, 0.5 per cent NaCl and 0.07–0.13 per cent Fe_2O_3. A specially pure sulfate from Knothe and Fritsche, Bodenback, showed 99.72 per cent Na_2SO_4, 0.08 per cent NaCl and 0.0009 per cent Fe_2O_3. C. H. KERR.

The common processes of decorating glass. CARL JUNG. *Sprechsaal*, **53**, 107–8, 119–20, 129–31, 138–41, 145–7 (1920).—The decoration is as old as the making of glass. The various processes are described in considerable detail under the headings: (1) those caused by manipulation of the glass batch; (2) soft glasses with suitable furnace treatment. These fall into 3 classes: (*a*) by fashioning, (*b*) by a layer of other glass on the hot glass body, (*c*) by other means; (3) those applied to cold glass and (4) combinations of (1)-(3). Many details are given. C. H. KERR.

Measurements of the thermal dilatation of glass at high temperatures. C. G. PETERS AND C. H. CRAGOE. Bur. of Standards, *Sci. Paper* 393 (1920).—The methods and results of an investigation of the thermal expansion and the chemical composition of different kinds of optical glass, chemical glassware, and commercial tubing are presented in this paper. A ring of the glass, placed between two fused quartz plates, was heated in an electric furnace and its expansion measured by the Fizeau interference method. Observations were made in the temperature regions between 20° and 650° C. on 32 different kinds of glass. Their dimensional changes are represented by curves which show that the glass passes through a critical expansion region, in which the expansion rate increases by 2 to 7 times. This critical region, which for any one glass does not exceed 40°, was found as low as 400° C. with one glass and as high as 575° C. with another. About 75°

above the critical region the glass softens and contracts. A comparison of results shows that the heat absorption observed by Tool and Valasek occurs in the same temperature region as the critical change in the expansion.

A. J. LAMBERT

Glass for pressed ware. ANON. *Glasindustrie*, **31**, 81–2(1920). The glass must not lose it fire polish during pressing. As a rule about 3–5 kg. KNO_3 per 100 SiO_2 is required to make the glass workable. Good formulas are:

	Crystal	Clear	Grayish	Rose red	Turquoise blue	Milk white
Sand	100	100	100	100	100	100
K_2CO_3	12	15	5	10	40	10
Na_2CO_3	23	17	30	24	...	15
$CaCO_3$	14	13	14	11	...	13
Pb_3O_4	5	...	...	...	3	...
KNO_3	5	2	3	3	4	5
As_2O_3	0.5	...	...	...	...	...
NiO	...	0.003	0.003	...	...	...
Witherite	...	...	...	24	...	...
Gold	...	...	...	0.005	...	...
Bone ash	...	...	...	...	7	...
Asbestos	...	...	...	...	4	...
$CuSO_4$	...	...	...	...	$1^1/_2$	...
Cryolite	...	...	...	...	...	15

C. H. KERR.

Bottle glass. ANON. *Glasindustrie*, **31**, 89–90(1920).—Twelve formulae are given for white, green, blue-green, brown and yellow glasses.

C. H. KERR.

Plate glass. ANON. *Glasindustrie*, **31**, 89 (1920).—Nine formulae for plate glass and window glass are given, including formulae for aquamarine blue and antique green. C. H. KERR.

Practical developments with substitutes in glass decoration. ANON. *Glasindustrie*, **31**, 73–4 (1920).—A much wider use of sand-blasting, staining and paper decoration has resulted from war conditions. C. H. KERR.

PATENTS

Apparatus for drawing glass sheets. HALBERT K. HITCHCOCK. U. S. 1,349,201, Aug. 10, 1920. A container for glass approximating in length the width of the glass sheet to be produced and comprising side and end walls downwardly and inwardly inclined, and heating chambers along the side walls only.

Means for transferring hot glass. MICHAEL J. OWENS. U. S. 1,350,464, Aug. 24, 1920. An apparatus with a trough, means to deliver hot glass

thereto, and means to revolve the trough about an axis extending lengthwise of the trough.

Glass-working machine. EDWARD MILLER. U. S. 1,350,375, Aug. 24, 1920. The combination with a movable table, molds comprising relatively movable parts carried by the table, a reciprocal table actuator, a primary air valve shifted by the actuator, a pneumatically operated secondary air valve controlled by the primary air valve, air-pressure motors controlled by the secondary valve, and connections between said air-pressure motors and the molds.

Glass-gathering mechanism. AUGUST KADOW. U. S. 1,350,552, Aug. 24, 1920. This describes an apparatus for manufacturing glass, with the combination of a vessel to contain molten glass, gathering mechanism and means for moving the same over the glass in the vessel. This mechanism comprises a gathering mold, an oscillatable elbow-shaped supporting device for the mold, means for oscillating the same while the gathering mechanism is over the vessel so as to bring the gathering end of the mold into and out of contact with the glass. The mold comprises separable elements, and means for opening and closing the same.

Apparatus for conveying molten glass. JOSEPH B. GRAHAM. U. S. 1,350,448, Aug. 24, 1920. This apparatus has means for discharging molten glass, and a switch device comprising a plurality of means for receiving and directing the glass to different positions. The receiving and directing means are brought individually into operative position by the movement of the switch, the latter having an intermediate position permitting the glass to be discharged independently of the receiving and directing means.

Sand and slime separator. JAMES D. MCDONALD. U. S. 1,350,509, Aug. 24, 1920. In a slime and sand separator, the combination with a casing having an inlet at one end, a slime outlet at the other end, and a sand outlet at one side. An outer reel is rotatably mounted within the casing and has blades moving past said sand outlet, and an inner reel is mounted within the outer reel and rotates in the opposite direction, both reels having skeleton heads.

Glass-feeding machine and process. KARL E. PEILER. U. S. 1,349,551, Aug. 10, 1920. The combination with a container for molten glass having a discharge outlet, of supporting means beneath the outlet adapted to suspend discharged masses of the glass, and means for periodically tilting said supporting means to time the formation of suspended masses. The method of separating molten glass into mold charges which consists in flowing the glass onto a support, periodically tilting the support to form successive gathers of the glass suspended from the support, and severing a mold charge from each gather.

C. M. SAEGER, JR.

Lamp shades, and so forth; silvering; varnish. E. M. BENNETT. Brit. 137,887, Jan. 2, 1919. A reflecting lamp shade or globe of transparent glass has its outer surface silvered or otherwise provided with a reflecting surface, and its inner surface formed with integral projections to refract and distribute the reflected rays. The projections may be of pyramidal, diamond, or jewel shape and have flat, concave, or convex sides. The reflecting medium is covered with a protective coating such as elastic varnish composed of 10 parts dammar gum, 3 parts asphalt, 5 parts gutta-percha, and 75 parts benzene. A suitable silvering compn. is made from 175 grs. $AgNO_3$ and 10 oz. distd. H_2O, 262 grs. NH_4NO_3, and 10 oz. of distd. H_2O, 50 grs. tartaric acid dissolved and boiled for 10 min., and, when cool, added to 1 oz. alc. and distd. H_2O sufficient to make up 10 oz. Equal parts of the ingredients are mixed together and the shade or globe, after being cleansed, is suspended outer-face downwards in the liquid for 20 to 80 min. [*C. A.*]

Whiteware and Porcelain

The mechanical properties of ceramic bodies and exact testing methods of same. E. ROSENTHAL. *Berichte der Technisch-wissenschaftlichen Abteilung des Verbandes keramischer Gewerke in Deutschland*, **5**, 23–33(1919).—The mechanical strength of ceramic wares is important not only for technical porcelain but also for a large number of other wares, such as hotel ware, table porcelain, stoneware and electrical porcelain. Considerable has been published on the tens. strength, compress. strength and cross bending strength but little has been done to meas. the resistance of ceramic wares to impact and torsion. The compress. strength of porcelain is about 4000 kg./sq. cm., tens. strength is 140–160 kg./sq. cm. and cross bending strength is about 500 kg./sq. cm. A weight suspended as a pendulum is used to meas. the resistance to impact. An apparatus used to meas. the torsion of ceramic bodies is described. H. G. SCHURECHT.

Porcelain token money. ANON. *Chem. Met. Eng.*, **23**, 297 (1920).—The city of Meissen and other towns have ordered porcelain coins for local use to solve the small-change scarcity and obviate the present unclean and easily tearable paper currency. Germany is said to be about to introduce porcelain small-change coins. A. J. LAMBERT.

Enamels

The relation of composition to the softening point of enamels. Bur. of Standards, *Tech. News Bull* **40** (1920). Anonymous.—The Bureau has undertaken a study of the relation of composition to the softening point of enamels. From the data obtained so far it may be stated that the effect of various constituents on the softening point is not in accord with the chemical similarity of these constituents. For instance, certain basic oxides act as refractories in enamels, while others act as fluxes. The same is true for the so-called intermediate oxides and the acid oxides. In a given chemical group

of oxides the fluxing effect is not in proportion to the molecular weight, and on the other hand equal percentage amounts of the various oxides do not have the same fluxing effect. The action of each oxide and mineral used in compounding enamels seems to be characteristic of that particular mineral or oxide and can not be calculated by any system of *a priori* reasoning.

A. J. LAMBERT.

Fish scaling of sheet steel enamels. Bur. of Standards, *Tech. News Bull.* **41** (1920). Anonymous.—As one phase of a comprehensive investigation of this subject, the relation of cold-working of the steel, such as is undergone by steel shapes which are pressed into form before enameling has been studied. It has been found in a number of cases that stretching the steel eliminated fish scaling which had occurred on unstretched steel of the same lot. These results confirm the observations made in practice that those parts of vessels which have been spun or stretched in shaping are often free from fish scaling in enamel, while the parts that have not been stretched contain fish scales.

A. J. LAMBERT.

Relation of composition of enamel to solubility in acids. Bur. of Standards, *Tech. News Bull.* **41** (1920). Anonymous.—During the progress of this investigation, it was noticed that in a large number of cases enamels scratched to some extent after being subjected to the action of boiling acid for only a few hours but after continued treatment would not scratch at all. This led to the conclusion that possibly the boiling acid had some annealing effect upon the enameled surface that made it more resistant. It has been found that boiling enamels in oil for several hours before subjecting them to the acid treatment entirely eliminated this preliminary scratching and softening of the surface. Boiling in water had a similar but not as great an effect as boiling in oil, while simply heating the pieces in air had little effect. It would seem advisable to treat with boiling oils all enameled wares which are to be subjected to the action of corrosive liquids.

A. J. LAMBERT.

Brick and Tile

Some brick-iron problems. J. SCOTT. *Brit. Clayworker*, **29**, 114–115 (1920).—Although 5 per cent ferric oxide in some clays does not yield a striking redness in some clays, 3 per cent of it in others will often give a pronounced red. In the clay from which buff-colored brick are prepared the iron is often present as pyrites, *i. e.*, iron sulphide or disulphide. The richer a clay is in alumina the more likely it is to burn off buff rather than red. If sufficient chalk or lime is mixed with an ordinary red burning clay, the brick from it, when fired below 800° C. remain red; but when fired above this temp. the chalk reacts with the lime-making the brick buff. When buff brick are examined under the microscope the pigments have the appearance of magnetic iron oxide.

H. G. SCHURECHT.

Paving-brick and method of making the same. FRANK W. WOOD. U. S. 1,350,764, Aug. 24, 1920. A paving brick having projections on its side with each projection surrounded by a recess extending into the body of the brick at the base. The method of forming paving brick with projections on the side which consists in first forming the brick and then subjecting them to a re-pressing operation under a die having depressions surrounded by projecting cup-shaped rims.

Paving. NORTON CO. Brit. 138,865, Jan. 24, 1920. A non-slipping paving or tread consists of cryst. grains of a hardness of 9 or more, such as corundum, emery, fused Al_2O_3, SiC, and so forth, bonded into chips $^1/_4$-2 in. in size by a ceramic material, the chips being embedded in cement, asphalt, and so forth, to form a surface-layer. The ceramic material consists of 44 parts by wt. of slip clay, 44 parts of feldspar, and 12 parts of ball clay. The ingredients are crushed, mixed dry with the crystals, damped and pressed into lumps, and fired at about 1300° for 50 to 100 hr., then cooled slowly and crushed to size. The foundation may be formed by excavating, laying crushed stone and adding successive layers of stone and cement to form the bed. The matrix for the top layer may consist of hydraulic or Mg oxychloride cement, or resinous or bituminous material. Cf. *C. A.* **14**, 2065. [*C. A.*]

Abrasives

PATENTS

Abrasives. N. C. HARRISON. Brit. 137,490, July 14, 1919. An abrasive is made by fusing in the elec. furnace calcined disapore, Fe such as ground cast-iron borings, and coke, preferably in the proportions of 17:2:3, and cooling slowly with or without agitation. It consists of corundum with some ferrosilicon; no slag is formed. [*C. A.*]

Cement and Lime

Colored plasters. Bur. of Standards, *Tech. News Bull.* **41**, (1920). Anonymous.—It has been found possible to make colored wall plasters of any desired color or texture by use of dyed wood fiber in gypsum plaster. Panels of this material have been submitted to the Gypsum Industries Association in Chicago, and a publication on the subject is now being prepared.

A. J. LAMBERT.

Utilization of low-grade fuel and increased efficiency in portland cement manufacture. ANON. *Chem. Age* (*N. Y.*) **28**, 205–7 (1920).—By a recent invention of Robert W. Lesley (cf. *C. A.* **14**, 330) oil shale, lignite, low-grade bituminous and cannel coal, and so forth, can be used as fuels in the manuf. of portland cement, and at a considerable saving. The low-grade fuels are destructively distd. in retorts, the retorts being placed between the rear end of the rotary kiln and the flue. The kiln gases pass off at 1000°–1400° F., while the

temps. required for the distn. of the fuels referred to above, range from 800° F. for light oils to 1300° F. for heavy oils. The oil and $(NH_4)_2SO_4$ resulting from the distn. are recovered as usual, the gas is carried to the front end of the kiln and used as fuel while the coke residue, which is usually high in ash, is conveyed to the kiln hopper and fed in with the other cement raw materials. The C content of the coke aids in the combustion within the kiln, while the ash, which is usually argillaceous, produces good clinker after it has been mixed in the kiln feed hopper with the proper amt. of calcareous material. The distn. retorts do not interfere with the recovering of potash from the spent flue gases. [*C. A.*]

ACTIVITIES OF THE SOCIETY

Important Actions of the Board of Trustees at the Chicago Meeting, August 16, 1920

It was voted to raise the price of a complete set of the Transactions to $150.00, subject to 40% discount to members. Five sets are to be reserved for disposal by vote of the Board of Trustees only.

It was voted to hold the 1921 Annual Meeting in Columbus, and Professor A. S. Watts was appointed chairman of the local committee.

Mr. F. H. Riddle was appointed a committee to draw up a code of ethics covering the relationship between the ceramic engineer and the owner of the factory, with regard to the patenting of ceramic formulas, and so forth.

Mr. H. F. Staley's resignation as Editor of the Journal was received, and his offer to retain the position if necessary until the beginning of the new year was accepted.

New Members Received during September

Resident Associate

Adams, Lewis A., Mansfield, Ohio, Superintendent, Mansfield Vitreous Enameling Company.

Fitz-Gerald, Gerald, Muncie, Indiana, Maxon Furnace and Engineering Company.

Gassman, H. M., 848 Brown-Marx Bldg., Birmingham, Ala., Consulting Engineer.

Legg, Victor E., 330 Vinewood Ave., Detroit, Mich., Research Physicist, Detroit Edison Company.

Marshall, P. M., 195 Broadway, New York City, Purchase Engineer, Western Electric Company, Inc.

Mitscherling, W. O., Ph.D., Landing, N. J., Atlas Powder Company.

Nolan, C. J., Toledo, Ohio, General Manager, Modern Glass Company.

O'Hara, Eliot, 46 Greenwood Lane, Waltham, Mass., Manager, O'Hara Waltham Dial Company.

Ragland, Nugent A., 1006 S. 5th Street, Champaign, Ill.

Richardson, P. B., 1018 Marine Trust Bldg., Buffalo, N. Y., Salesman, Harbison-Walker Refractories Company.

Roberts, Frank G., Baltimore, Md., Service Engineer, Porcelain Enamel and Manufacturing Company.

Schramm, Edward, 574 Whittier Ave., Syracuse, N. Y., Research Chemist, Onondaga Pottery Company.

Stover, J. Homer, 176 Grant Ave., Nutley, N. J., Sales Manager, John Johnson Company, Brooklyn, N. Y.

Wright, Marcus S., South River, N. J., Miner and Shipper, Foundry Sands and Clay.

Foreign Associate

Bateson, H. A., Liverpool, England, Glass Bottle Manufacturer.
Fogelberg, Sven, Kosta, Sweden, Assistant to Direktor, Kosta Glass Works.
Gass, George P., "The Hollins," The Haulgh, Bolton, England, Director, Entwish & Gass, Ltd.
Gregg, Henry, Knottingley, England, Gregg & Company.
Orrell, John, Thorold, Ont., Canada, cr Pilkington Bros.
Rees, W. J., 102 Ivy Park Rd., Ranmoor, Sheffield, England, Head of Refractories Research Dept., University of Sheffield.
Shibata, R., 41 Kaminku, Tokyo, Japan, Professor, Higher Technical School.
Snowdon, William C., 24 Beaconsfield St., Acomb, York, England.

The Entertainment of the Ladies at the Next Convention

The entertainment of the ladies who will attend the next annual convention in Columbus, Ohio, February 21 to 24, 1921, has been placed in charge of Mrs. Arthur S. Watts, 1764 North High St., Columbus, Ohio.

Mrs. Watts has announced her intention of making this a feature of the coming convention and desires to get into communication with every lady who hopes to attend the convention whether she has made definite plans to do so or not.

If you have never taken your wife to an American Ceramic Society Convention, you have missed a source of real pleasure both to her and yourself.

The ladies should communicate with Mrs. Watts at the earliest possible moment so that a suitable program may be provided.

The Society at the Chemical Exposition

Was it worth while for the American Ceramic Society to maintain a booth at the Chemical Exposition?

One hundred and twenty-seven names on the register, sixty-five members and guests at the luncheon, nine hundred booklets and a hundred and fifty copies of the Journal distributed, fifty catalogs of the ceramic schools given out before the week was half over—these facts will furnish an answer. In addition, many inquiries about the Society and the schools were answered, technical questions were referred to the proper authorities, and headquarters service was rendered as far as possible.

Interest among the general public was aroused by means of a small exhibit of bone china, loaned by Lenox, Inc., a number of aventurine vases by Mr. Minton, some decorated ware loaned by Roessler and Hasslacher Chemical Company, and a model of a nitric acid plant, loaned by the General Ceramics Company. The Transactions and Journal of the Society, with its other publications, and photographs and literature from the various ceramic schools were also exhibited and created opportunities for publicity.

Ceramic Day, Friday the 24th, was well attended. The luncheon held at the Hotel Commodore was a real success, and an interesting program was presented in the afternoon, consisting of the following papers:

"The Potter's Art and the Chemist's Science," R. H. Minton.

"Decorative Architecture," Leon V. Solon.

"The Influence of the Artist in Industrial Ceramics," J. Munro Hewlett.

"Report of the Committee on the Definition of 'Ceramic'," read by Charles F. Binns.

"A Classification of Sheet Steel Enamels," R. R. Danielson.

"Possibilities for Research and Development in the Field of Refractories," H. F. Staley.

The contributions by Mr. Solon and Mr. Hewlett aroused much interest because they differed from the papers and addresses which have hitherto formed the bulk of the Society's literature, both dealing with certain phases of art work. Mr. Hewlett, a prominent architect, advanced the theory that the manufacturers of clay wares, notably terra cotta, should show more initiative in the leading of public taste. This aroused some discussion, and it was pointed out that the manufacturers are, to a large extent, obliged to obey the specifications of the architect. The other papers were also of high grade.

In the evening a number of industrial moving pictures were shown, among them one on the manufacture of pottery, loaned by the Rookwood Pottery. A film on the manufacture of electric lamp bulbs, loaned by the Nela Park Laboratories, arrived too late for the program.

The ceramic industry was well represented at the Exposition. The exhibits of chemical stoneware, chemical porcelain, glass, enameled iron, kilns, dryers, furnaces, pyrometers, and other equipment attracted favorable comment.

CHAS. F. BINNS, *Secretary*

Meeting of the Northern Ohio Section

The tenth meeting of the Section was held in Elyria, Ohio, October 4th. An early start was made to the plant of The Elyria Enameled Products Company, who are manufacturers of steel and cast iron enameled apparatus for the dairy, canning and chemical industries. All details of the plant were carefully explained and an inspection of the new ceramic and chemical engineering laboratories was made.

Lunch was served at the Y. M. C. A., at which we were guests of the Elyria Enameled Products Company. After lunch a business session was held and the following technical program was submitted:

"Technical Control and Research in an Enameling Plant," B. A. Rice, Ceramic Chemist, Elyria Enameled Products Company.

In this paper the detail involving plant control was outlined and those present interested in this line of work could appreciate the efforts of the writer.

"The Uses of Enameled Apparatus," Max Donauer, Sales Chemist, Elyria Enameled Products Company.

In this paper it was plain to be seen that this company tries to anticipate the use of their product and then watches the abuse to which it is subjected.

"The Development of the Enameling Industry during the Last Fifteen Years," R. D. Landrum, Service Manager, Harshaw, Fuller & Goodwin Co., Cleveland.

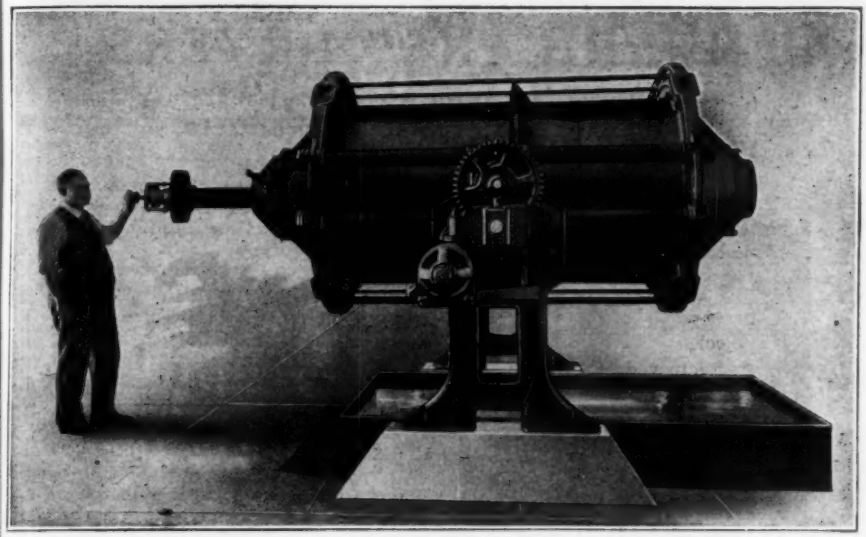
This subject was ably presented by the author, who was one of the very first to specialize in enameling research and has extensively published papers on this subject.

"The Refractory Problems of the Enameling Industry," E. P. Poste, Chemical Engineer, Elyria Enameled Products Co.

Mr. Poste gave an extemporaneous talk on refractories from live items in his note book and many could realize the grief almost every manufacturer has who is dependent upon any great amount of heat for results.

We were privileged to have with us for the day Mr. Homer F. Staley who kindly responded to a request for a speech. His closing remarks were an appeal for every member to hustle advertising for the Journal.

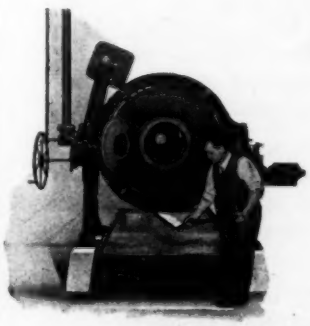
CHARLES H. STONE, JR., *Secretary*



Melting Enamels In The Rotary Furnace.

SMELTING enamel in a brick oven is a slow, costly process. But in the U. S. Furnace a batch is turned out every two hours, easily and economically.

Capacities 700 lbs. and 1200 lbs. of enamel a heat.



The U. S. Furnace slowly rotates as the material melts. A white heat occurs in the melting chamber. The fuel is oil or gas. The rotary motion of the melting chamber produces a uniform and high grade enamel and the cost and labor is less.

All colors of enamel or porcelain frit for structural or household wares can be smelted in the U. S. Furnace.

Photographs, specifications and prices mailed promptly.

U. S. SMELTING FURNACE CO.
BELLEVILLE, ILLINOIS

"HURRICANE" DRYERS

Stove Rooms and Mangles for Clay and Porcelain Products

Automatic Machine for Dry Pressed Electrical Porcelain.

During the past several years we have made many successful installations for handling Electrical Porcelain, both for standard dry pressed ware, and special insulators of large size.

Our Automatic Conditioning Machines for clay rolls and spark plug blanks are materially shortening the time and producing a superior, uniformly dried product.

Also Truck and Continuous Machines for molds and saggers.

The Philadelphia Drying Machinery Co.

Main Office and Works
Stokley St. above Westmoreland

Philadelphia

Boston Office
53 State St.

Zwermann *Twin* Tunnel Kiln

Note Its Chief Advantages:—

First:—The first cost of this kiln compared with a single tunnel of the same capacity is considerably lower. It requires less brick, one-half of the buck stays, less space, and no side or return track.

Second:—This twin tunnel kiln allows a greater utilization of the fuel than a single tunnel kiln, as the heat from cooling ware is used for water-smoking the incoming ware.

Third:—This kiln allows an absolute and positive control of the firing zone, and in the firing zone a reducing or oxidizing condition can be maintained at will.

Fourth:—The cooling of the ware as well as the water-smoking and pre-heating in this kiln are absolutely automatic. It is impossible to get the receiving end of the tunnel too hot.

Fifth:—This kiln will save about 50% on labor and from 65% to 75% on fuel as compared with periodic kilns. Burning time is cut down by ⅓ to ½. Where saggers are used, they will last twice as long.

Carl H. Zwermann **Robinson, Ill.**

FELDSPAR

Spotless Grade, Pure Mineral, from our Quebec Quarries.
Crude Spar for particular potters.

Orders being received for 1921 delivery

O'BRIEN & FOWLER
410 Union Bank Bldg.,
OTTAWA, CANADA

We Have Faith in Our Goods so we Advertise Here—

The Underwood Producer Gas System, patented, saves fuel and labor in burning clayware, baking carbon products, roasting ores, heating lehrs in glass factories, also revolving pots, etc. and enameling metal ware.

The Justice Radiated Heat and Waste Heat Dryers for drying structural clayware have no equal in economy and efficiency.

"Meco" Single Roll Rock and Shale Crushers, Elevators, conveyors, and feeders make up the most complete clay preparing outfit, a necessity in every clay plant when material must be ground and screened. Write us about three things. To answer is our pleasure.

THE MANUFACTURERS EQUIPMENT CO.

Dayton Ohio, U. S. A.

THE EXPERIENCED BUYER
OF
ACID-PROOF CHEMICAL STONEWARE

wants his material ACCURATE IN DIMENSIONS and DEPENDABLE TO RESIST CORROSION.

OUR WARE MEETS BOTH CONDITIONS

That is why we manufacture at least two-thirds of the entire output of CHEMICAL STONEWARE within the U. S. A.

GENERAL CERAMICS COMPANY
50 Church Street
NEW YORK CITY

"EQUIPPED TO SUPPLY A PLANT OR A NATION"

MANUFACTURERS ALSO OF A COMPLETE LINE OF FUSED SILICA

WANTED

For industrial position—Engineer with knowledge of ceramics. State age and salary expected. Address "Box 75," care This Journal.

POTTERY MANAGER

First class ceramic engineer with theoretical, as well as practical pottery experience; one who understands the chemistry of clays for the manufacture of tile and general ware and can take charge of a large plant of thirteen kilns. Must be able to handle men. State past experience, salary required, and class of ware previously manufactured. Address "Box 387–B" care This Journal.

WANTED

TRANSACTIONS OF THE AMERICAN CERAMIC SOCIETY

Volumes II, V, IX, X, XII, XIV, and XIX.

Five dollars will be paid for each copy in good condition.

Charles F. Binns, Secretary
Alfred, New York

Main Office
New York City

The Roessler & Hasslacher Chemical Company

High Grade

CHEMICALS

Minerals Oxides

GOLD & SILVER

Preparations

Colors, Lustres, Bodies and Oxides

Branches

Chicago
Boston
New Orleans
Cleveland
Philadelphia
Trenton
San Francisco
Cincinnati
Kansas City
Akron

Insulation Increases Kiln Capacity

Waste heat means waste dollars. Insulate your kilns with **SIL-O-CEL** MADE FROM CELITE after the plans approved by our engineers and make your kilns more productive, less fuel and more even kiln temperatures. SIL-O-CEL insulation prevents heat penetration. Write for Bulletin-5A.

CELITE PRODUCTS COMPANY

NEW YORK, 11 BROADWAY · CLEVELAND, GUARDIAN BLDG · ST. LOUIS, 1532 OLIVE STREET
PHILADELPHIA, LIBERTY BLDG · DETROIT, BOOK BUILDING · LOS ANGELES, VAN NUYS BLDG
PITTSBURGH, OLIVER BLDG · CHICAGO, MONADNOCK BLDG · SAN FRANCISCO, MONADNOCK BLDG

Quality *Uniformity* *Experience*

Edgar QUALITY *Clays*

REALLY washed—Highest percentage clay substance

Brands	*Produced by*
Edgar Florida Kaolin	*Edgar Plastic Kaolin Co.*
Edgar Georgia Paper Clay and Kaolin	*Edgar Brothers Co.*
Lake County Florida Clay	*Lake County Clay Co.*

One Management — Office, Metuchen, N. J.

New York State School of Clay-Working and Ceramics

ALFRED, N. Y.

Courses in Ceramic Engineering and Applied Arts

TUITION FREE

Opportunities for graduates are numerous and attractive

Write for Catalog

Charles F. Binns, Director.

Save Fuel and Time

By the use of Brown Pyrometers, Ceramic Plants are saving from 10 to 12 tons of coal and from 56 to 90 hours, per kiln, and increasing their percentage of "firsts" 21%. Write for particular today to The Brown Instrument Co., 4513 Wayne Ave., Philadelphia, New York, Pittsburgh, Detroit, Chicago, St. Louis, Denver, San Francisco, Los Angeles or Montreal.

Brown Pyrometers

The World's Standard Heat Meter

WANTED

CERAMIC ENGINEER

Trained ceramic engineer wanted to take charge of laboratory, application of glazes, and eventually supervise the burning in a large terra cotta plant. Answer, giving age, training, experience and salary expected. Address "A-1," care This Journal.

CERAMIC CHEMIST

wanted to do research work on clays in factory in New Jersey. Good prospects for man who can assist in improving product. Answer, stating age, education, past position, if any, and salary expected to start. Address "Box 175," care this Journal.

ENGLISH
AND
DOMESTIC

CLAYS
FOR
ALL
CERAMIC
PURPOSES

—PMCCO—
MEANS SERVICE, QUALITY AND PRICE

PAPER MAKERS CHEMICAL CO., EASTON, PA.

VITRO
CHEMICALS

SELENITE of SODIUM

ARTIFICIAL CRYOLITE
for white and opalescent glass

SODIUM SILICO FLUORIDE

UNDERGLAZE COLORS
for high temperatures

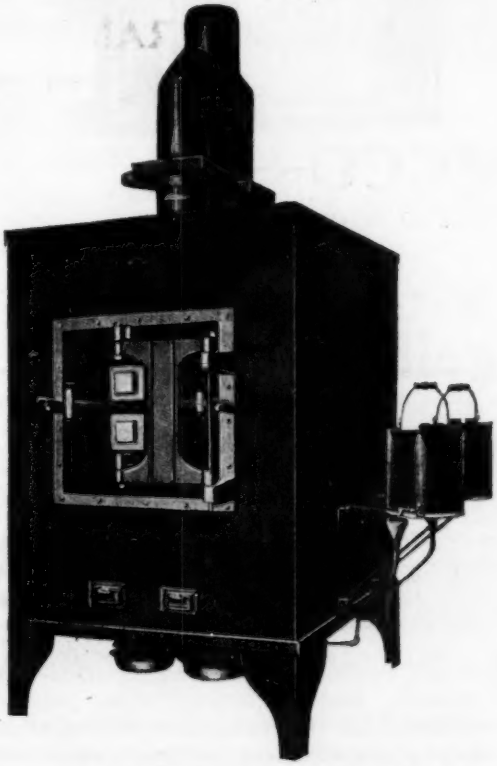
POTTERY GLAZES & ENAMELS

The Vitro Mfg. Co. Pittsburgh, Pa

PERFECTION POTTERY KILNS

FOR FIRING BISCUIT, CLAY BODIES AND GLAZES.

EQUIPPED FOR KEROSENE OIL,
MANUFACTURED AND NATURAL GAS.

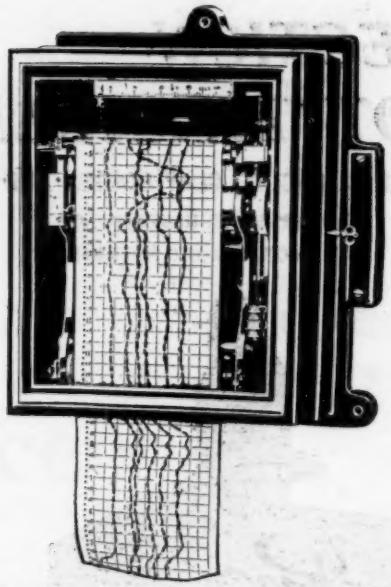


NO. 12 PERFECTION POTTERY KILN
Equipped with Kerosene Oil Burners.

B. F. DRAKENFELD & CO., Inc.

50 MURRAY STREET NEW YORK, N. Y.

ILLUSTRATED CATALOG MAILED ON REQUEST



Engelhard Pyrometers Excel in Service

PYROMETER SERVICE means accuracy, durability, adaptability, and freedom from those annoyances such as constant checking, sticking of the pointer, poor records, variations due to "cold end" temperatures, variations due to temperature coefficient in the instruments, line resistance errors, etc.

Why Engelhard Pyrometers excel in service is because they are "made right." Heavy thermo-couples guaranteed interchangeable within 3° C. Protecting tubes that stand up. Instruments of exceptionally high resistance as accurate as laboratory standards. Absolutely frictionless, built to stand abuse.

INVESTIGATE

Charles Engelhard

30 Church Street New York. N. Y.

Make Better Products at a Lower Cost

The Proctor Dryer has four guaranteed claims of superiority over all other drying systems for the drying of lithopone, paint colors, white lead, aniline dyes, colors for printers' ink, chemicals and similar materials. These claims pertain to two items—cost and time, which spell efficiency.

The Proctor Dryer dries all materials in from one-fourth to one-tenth of the time required in most drying systems. Some materials are dried in 5 hours in a Proctor Dryer, while other materials are dried in 36 hours.

The Proctor Dryer requires only one-fourth to one-tenth the floor space of most drying systems.

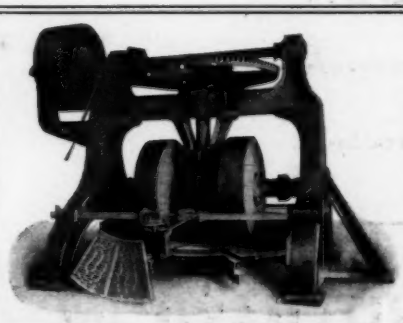
The Proctor Dryer is practically automatic in operation. The temperature is regulated by a thermostat, the amount of moisture in the dryer is under control, and the time of drying is absolutely constant—drying is independent of atmospheric conditions.

The Proctor Dryer is built entirely of metal and all bearings are located outside the machine away from the heat. This eliminates the possibility of heated bearings and consequent fires.

PROCTOR AND SCHWARTZ, INC.
CERAMIC EQUIPMENT DEPARTMENT
Philadelphia *Pa.*
Formerly Phila. Textile Mach. Co.

"Proctor" DRYERS

108



American Nine Foot Dry Pan

Here's one of our famous line of pans. They are built to handle a lot of clay and they do it. Nothing shoddy about this pan, that's why it makes good and works steadily without trouble. Get our pan printed matter. We surely have a pan to do your work better and with less trouble and expense than you are now doing it. Let us prove it.

The American Clay Machinery Co.
Bucyrus, O.

WANTED—SAGGER SCRAP

A few carloads of clean scrap or broken saggers are desired by new electrical porcelain plant.

In replying, please state quantity, price and the temperature at which the saggers were originally fired.

Address "Box 638,"
care This Journal.

ZIRCON, which is natural Zirconium Silicate, corresponds to kaolin, aluminum silicate. By analogy, it might have been predicted that the silicate would prove more suitable for ceramic work than the oxide.

It is idle, therefore, to attempt to regard Zircon or predict its behavior according to its content of Zirconium Oxide. As a matter of fact Zircon contains no Zirconium Oxide and no Silica, but only Zirconium Silicate, a distinct chemical compound having properties peculiar to itself.

ZIRCON

is used for super-refractories

and porcelains

BUCKMAN & PRITCHARD, INC.

MINERS AND MANUFACTURERS

MINERAL CITY, FLORIDA

New York Office, 94 Fulton Street

Chicago Office, 1350 Peoples Gas Building

HF&G

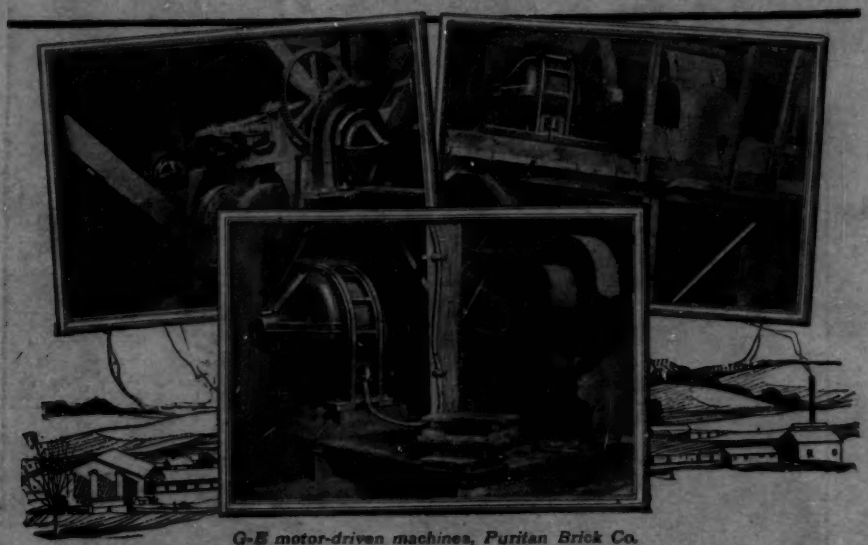
OXIDES

Aluminum	Lead
Antimony	Manganese
Chromium	Nickel, Black
Cobalt	Nickel, Gray
Copper, Black	Tin
Copper, Red	Titanium
Iron, Black	Zinc
Iron, Red	Uranium

Body Coloring Oxides

THE HARSHAW FULLER AND GOODWIN CO.
CLEVELAND-NEW YORK-PHILADELPHIA

Labor shortage and high fuel costs are being met in leading brick plants by using economical and efficient electric power equipment



G-E motor-driven machines, Puritan Brick Co. Camden, Ohio

25% Increased Output and 15% Less Power Cost

were the results obtained from G-E motor drive at one brick plant.

G-E motor drive eliminates line-shaft friction, reduces maintenance cost, runs each machine at its maximum productive speed and consumes no power when machines are not running.

Brick plants all over the country have installed G-E motors. Our engineers will be pleased to give you full details of a suitable drive for your plant.

General Electric Company

General Office Schenectady, N.Y.

Sales Offices in all large cities

43-256